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ABSTRACT

This collection of laboratory lessons is designed primarily for the non-college bound high school student. It can be adapted, however, to a wide range of abilities. It begins with an examination of the properties of nuclear radiation, develops an understanding of the fundamentals of nucleonics, and ends with an investigation of careers in areas related to nuclear radiation. Each experiment is integrated into the text. The small amount of reading material between labs is designed to bridge from one lab to another. (Author/RE)

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# INTRODUCTION TO NUCLEONICS

## A LABORATORY COURSE

U S DEPARTMENT OF HEALTH,
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## TEACHER GUIDE EDITION

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NUCLEAR RADIATION PROJECT STUDY

Sponsors:

The Illinois Division of Vocational and Technical Education, Research and Development Unit

High School District #155, Crystal Lake, Illinois

SE 029 864

# AUTHOR TEAM

## NUCLEAR RADIATION PROJECT STUDY

Co-director & author: Arthur Baker, Chairman, Science Department
Cary-Grove Community High School
Cary, Illinois

Co-director & author: William Phelps, Chairman, Science Department
Crystal Lake Community High School
Crystal Lake, Illinois

Author: Richard Alden, Physics Teacher
Crystal Lake Community High School

Author: Brendan Hawkins, Physics Teacher
Crystal Lake Community High School

Author: Harry McCauley, Physics Teacher
Cary-Grove Community High School

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# INTRODUCTION TO TEACHER'S GUIDE

## 1. General Philosophy

Introduction To Nucleonics is a laboratory course designed primarily for the non-college bound high school student. It can be adapted, however to a wide range of abilities. It begins with a look at the properties of nuclear radiation, develops an understanding of the fundamentals of nucleonics, and ends with an investigation of careers in areas related to nuclear radiation.

In developing the course, the authors have attempted to:

A. Use laboratory experiments to develop each concept.

B. Make each lab as inductive as possible.

C. Minimize the amount of reading necessary between labs.

D. Minimize the use of mathematics (except simple arithmetic).

E. Develop a logical sequence from lab to lab.

An example of the inductive nature of the laboratory work involves Chapter 2. In this chapter the student discovers that not all nuclear radiation has the same properties. He discovers different penetrating abilities, different tracks in cloud chambers, and different effects on Geiger tubes, photographic film, and dosimeters. Finally, he reviews the results of his experiments and catagorizes the properties of each type of radiation. Last of all, after he understands the properties, he attaches names (alpha, beta, and gamma) to each type of radiation.

## 2 Use of the Text

Each experiment is integrated into the text. The small amount of reading material (if any) between labs is designed to bridge from one lab to the next. The student should keep his laboratory notebook at hand. When he comes to a question labeled Q1, Q2, Q3, etc., he should answer it in his laboratory notebook before continuing.

If carbon copies of each lab are made, they can be collected prior to the post lab discussion (unless some questions are to be answered based on class data). The student will always retain the original copy of his data and his answers to questions.

The rows of asterisks at the end of some labs separate the lab from reading material. Make certain that the student realizes that the experiment ends at that point.

Throughout the text are a few exercises which are not parts of labs. These are included as a supplement to expand or reinforce a concept.

See supplementary reading list if a student wishes more information on a particular topic.

### 3. Role of the Student

As the student begins a lab he is attempting to find the answer to a question. Notice that most labs begin with an introductory question.

The student should understand the importance of good laboratory techniques and safety practices. He should establish a daily routine of reading and recording his dosimeter readings. He should be diligent in recording his observations and answering questions in his laboratory notebook.

The laboratory coats, film badges and dosimeters should add to the student's respect for working with radioactive materials. Care should be taken, however, to insure that his attitude is one of respect and not fear

### 4. Use of the Teacher's Guide

The following sections are included in this teacher's guide:

A. Objectives - The objectives tell what the student is expected to gain or understand from each lab. Quiz questions could be based on these objectives.

B. Estimated Schedule - This, of course, is flexible and may need to be altered to fit various length class periods and various ability students.

C. Estimated Time Per Lab - When a lab is to be done over a period of more than one day, this information is also included.

D. Materials - Materials are listed per lab group (2 people), unless otherwise noted. From this, the total amount needed for any size class can be determined.

E. Advance Preparation - If any preparation (other than setting out equipment) is necessary, it is explained in this section.

F. Hints - Safety practices, special techniques, pitfalls, and other information that may be helpful in doing the lab are included in this section.

G. Suggestions for Prelab and Postlab Discussion - The prelab and postlab discussion should constitute the major portion of the time spent in discussion with the entire class. Hints for these discussions are included in these sections.

H. Typical Results - This section will include actual student data and answers to questions. Often there is no single "correct" answer. In some cases, when a question is asked for a reason that is not obvious, the explanation is included in this section. It should be recognized that source activity will affect results. Our Gammator, for instance, was rated at 30,000 roentgen/hr. The level of activity of our other samples were 0.1$\mu$c for A, 0.1$\mu$c for B, and 1 $\mu$c for C. Different source activities may change specific results, but concept development should be the same.

5. Role of the Teacher -

Perhaps the major thing which the teacher should keep in mind as he teaches this course, is to resist the temptation to tell the student too much. A lab is not inductive if the student knows the answer before he begins.

The prelab discussions should be limited to special safety warnings and other information (such as the location of equipment) not given in the written lab instructions. Don't repeat all of the information given in the written instructions. If the student knows he must read the lab to learn what to do, he will read it; otherwise, he won't.

After the student begins work on the lab, the teacher should move from group to group looking for problems, giving hints if needed, and asking questions to test the student's understanding. By reading the answers to questions which the students have recorded in their notebooks, the teacher can often spot those students who need help In helping a student, try to ask a series of questions which will lead him to the correct answer, rather than telling it to him.

During the postlab discussion, the teacher should make certain that the major concepts, which were to be discovered in the lab, are understood by all students.

Aside from the prelab and postlab discussions, the teacher should spend very little time in discussion with the entire class

Finally, the teacher should do whatever possible to develop a sense of pride in each student concerning his laboratory work. Words of praise, from the teacher, can be the most effective means of maintaining an orderly, disciplined laboratory and encouraging good work habits

## SUGGESTED TIME SCHEDULES

Introduction to nucleonics can be taught as either a semester or a full year course. Following is a suggested outline for the full year course and three different options for a one-semester course. The full year course or semester course option #1 provides for students with a wide variety of abilities and interests.

Although we do not suggest ability or interest grouping, semester course options #2 and #3 are provided if students are already grouped as vocationally oriented or college preparatory.

### FULL YEAR COURSE

For a full year course (five 40-55 min. periods per week) Chapters 1 through 6 can be covered in their entirety. There will also be ample time for a rather full exploration of all three vocational areas in Chapters 7 through 9. Films (see film list) can be shown, as desired, throughout the course. If time permits some individually designed research type experiments might be done. A full year course might also permit a more "in depth" study of Chapter 5, which deals with nuclear theory. The AEC series "Understanding the Atom" may be used for supplemental readings.

## SEMESTER COURSE OPTION #1

A general course for students of average ability or students with a variety of abilities and interests.

To fit the shorter time schedule or 1 semester, 9 experiments in Chapters 1 through 5 have been marked as non-essential (See below). Some, or all, of these experiments can be omitted without seriously interrupting the continuity of the course. After Chapter 6, students will need to be selective in exploring the vocational applications in Chapter 7 through 9. A student may choose to work in one area of interest, or he may choose to select a few experiments from more than one area.

## SEMESTER COURSE OPTION #2

A course for students with strong vocational interests - generally non-college bound.

The non-essential experiments of Chapters 1 through 4 can be omitted entirely or in part. All of Chapter 5 can be omitted. These omissions should leave about 6 weeks for investigating the applications in Chapters 6 through 9.

## SEMESTER COURSE OPTION #3

A course for high ability students - generally college preparatory.

Chapters 1 through 5 can be covered in their entirety. Chapter 5 on nuclear theory might be explored more fully, perhaps through independent study. Chapters 6 through 9 may be omitted, or if time permits explored very selectively.

## NON-ESSENTIAL EXPERIMENTS

The following experiments may be omitted if semester Options #1 or #2 are followed.

2-8
2-10
2-11
2-12
4-6
4-7
5-1
5-2
5-3

Below are listed approximate time schedules for the four options just listed. They are not at all rigid and can be adjusted. They are intended to be rough guides for pre-planning.

| SCHOOL WEEK | YEAR COURSE | SEMESTER OPTION #1 | SEMESTER OPTION #2 | SEMESTER OPTION #3 |
|---|---|---|---|---|
| 1 | Ch 1 & 2 | Ch 1 & 2 | Ch 1 & 2 | Ch 1 & 2 |
| 2 | ↓ | ↓ | ↓ | ↓ |
| 3 | ↓ | ↓ | ↓ | ↓ |
| 4 | ↓ | ↓ | ↓ | ↓ |
| 5 | ↓ | ↓ | ↓ | ↓ |
| 6 | Ch 3 | Ch 3 | Ch 3 | ↓ |
| 7 | ↓ | ↓ | ↓ | Ch 3 |
| 8 | ↓ | ↓ | ↓ | ↓ |
| 9 | ↓ | Ch 4 | Ch 4 | ↓ |
| 10 | ↓ | ↓ | ↓ | ↓ |
| 11 | ↓ | ↓ | ↓ | Ch 4 |
| 12 | Ch 4 | Ch 5 | Ch 6 | ↓ |
| 13 | ↓ | ↓ | Ch 7,8,9 | ↓ |
| 14 | ↓ | Ch 6 | ↓ | Ch 5 |
| 15 | ↓ | Ch 7,8,9 | ↓ | ↓ |
| 16 | Ch 5 | ↓ | ↓ | ↓ |
| 17 | ↓ | ↓ | ↓ | Ch 6-9 |
| 18 | ↓ | ↓ | ↓ | ↓ |
| 19 | Ch 6 | | | |
| 20 | Ch 7 | | | |
| 21 | ↓ | | | |
| 22 | ↓ | | | |
| 23 | Ch 8 | | | |
| 24 | ↓ | | | |
| 25 | ↓ | | | |
| 26 | Ch 9 | | | |
| 27 | ↓ | | | |
| 28 | ↓ | | | |
| 29 | Independent study, research, AEC books | | | |
| 30 | | | | |
| 31 | | | | |
| 32 | ↓ | | | |
| 33 | ↓ | | | |
| 34 | ↓ | | | |
| 35 | ↓ | | | |
| 36 | ↓ | | | |

## DAILY SCHEDULE

Following is a suggested daily schedule for Chapters 1 through 5. It is based on class periods approximately 50 min. in length. Notice particularly the schedule for Chapter 3. Because of the living materials, several experiments are in progress at once. One of the Chapter 3 experiments (3-4) is started on day 13 in the middle of Chapter 2.

The schedule is intended only as a guide and can be easily altered. As presented it runs about 1½ weeks short of a semester. It includes all of the Chapter 1 through 5 experiments but allows no time for supplemental materials such as films.

The following alterations can be made for each of the suggested schedule options:

FULL YEAR COURSE

The addition of a few films, at proper places, and a slight expansion of Ch. 5 will complete Ch. 1-5 at the semester as suggested. Semester 2 covers Ch. 6-9 plus supplemental materials.

SEMESTER OPTION #1

Deletion of the non-essential experiments will allow about 4½ weeks for Ch.6-9.

SEMESTER OPTION #2

Deletion of the non-essential experiments and Ch. 5 will allow about 6 weeks for Ch. 6-9.

SEMESTER OPTION #3

Follow schedule as presented using final 1½ to 2 weeks for selected experiments from Ch. 6-9.

| DAY | |
|---|---|
| 1 | Pre-lab & Experiment 1-1. |
| 2 | Assign lab groups, lab stations & discuss lab safety. Place discs on film for Exp. 2-1. |
| 3 | Complete Exp. 2-1. |
| 4 | Postlab 2-1, Pre-lab 2-2. |
| 5 | Exp. 2-2. |
| 6 | Postlab 2-2, read pp 12 & 13 in class. |
| 7 | Class Exp. 2-3. |
| 8 | Prelab - Experiment postlab 2-4. |
| 9 | Prelab & Exp. 2-5. |
| 10 | Postlab 2-5, prelab & begin 2-6. |
| 11 | Finish 2-6 & postlab. |
| 12 | Prelab - experiment, postlab 2-7. |
| 13 | Irradiate beetles for 3-4 (needed in 4 weeks) don't discuss now. |
| 14 | Prelab & Exp. 2-8. |

15 Postlab 2-8, prelab 2-9.

16 Exp. 2-9 & postlab.

17 Prelab & Exp. 2-10.

18 Check beetles (Exp. 3-4). Postlab 2-10, plan for lab test.

19 Lab test Ch. II.

20 Prelab & Exp. 2-11.

21 Postlab 2-11, prelab 2-12.

22 Exp. 2-12 & postlab.

23 Check beetles (Exp. 3-4). Test Ch. 1 & 2.

24 Discuss test, prelab & place materials for 3-1 in Gammator.

25 Finish 3-1 & postlab.

26 Prelab 3-2, Part I - Exp. 3-2

27 Set up for Part II - Exp. 3-2, Part III - Exp. 3-2 (postlab in 1 week).

28 Check beetles (Exp. 3-4) sort seeds, calculate dose & irradiate (3-5).

29 Plant seeds for 3-5. Put beetles in Gammator for 3-3.

30 Finish & postlab 3-3.

31 Discuss idea of Exp. 3-4 (in progress) & share data to date.

32 Check dosimeters for 3-2, postlab 3-2 (entire experiment).

33 Final beetle check (3-4) & postlab.

34 Finish Exp. 3-5 (harvest, measure, etc.).

35 Postlab 3-5. Begin 3-6 (dry lab) finish for class tomorrow.

36 Postlab 3-6, prelab 3-7.

37 Exp. 3-7.

38 Prelab and put fish for 3-9 in aquaria.

39 Prelab & begin Exp. 3-8.

40 Finish 3-8 & postlab.

41 Dissect fish and prepare autoradiograph for 3-9.

42 Develop autoradiograph & postlab 3-9.

43 Begin Exp. 3-10.

44 Finish 3-10 & postlab. Discuss pp 78-80.

45 Test Ch. 3.

46 Discuss test. Begin work on Appendix E.

47 Finish Appendix E. Discuss & prelab 4-1.

48 Exp. 4-1 & work on graph.

49 Postlab 4-1, prelab & start 4-2 (up to 24 hr. wait).

50 Check 4-2, prelab & begin 4-3.

51 Check 4-2. Finish 4-3. Calculate & graph results.

52 Check 4-2, postlab 4-3, prelab 4-4.

53 Check 4-2, Exp. 4-4 & postlab.

54 Check 4-2, & postlab 4-2, prelab 4-5.

55 Exp. 4-5.

56 Postlab 4-5. Discuss pp 93, 94. Prelab 4-6.

57 Exp. 4-6 & postlab.

58 Prelab - experiment - postlab 4-7.

59 Prelab & Exp. 4-8.

60 Postlab 4-8. Discuss pp 99, 100. Work on Exercise 4-1.

61 Discuss Exercise 4-1. Prelab & begin 4-9.

62 Finish 4-9.

63 Work on 4-9 calculations.

64 Postlab 4-9 & discuss pp 105-108 (Exercise 4-2 in class).

65 Exercise 4-3 & discuss.

66 Test Ch. 4.

67 Discuss test. Discuss pp 110, 111. Assign Exercise 5-1.

68 Discuss Exercise 5-1. Prelab Exp. 5-1.

69 Exp. 5-1.

70 Postlab 5-1 Plan Exp. 5-2 (mini experiment)

71 Exp. 5-2 & postlab.

72 Discuss pp 114, 115. Exercise 5-2.

73 Discuss Exercise 5-2. Discuss pp 116-118. Do Exercises 5-3 & 5-4.

74 Discuss Exercises 5-3 & 5-4. Prelab 5-3.

75 Exp. 5-3, Part I.

76 Begin Exp. 5-3, Part II.

77 Finish Exp. 5-3, Part II.

78 Postlab Exp. 5-3. Discuss pp 124-128. Assign Exercise 5-5.

79 Discuss Exercise 5-5. Discuss pp 128-137.

80 Finish discussion & review Ch. 5.

EQUIPMENT FREQUENTLY USED (excluding equipment usually found in high schools)

A complete list of the equipment needed for the course is given at the end of this Teacher's Guide.

The following is a list of apparatus that you may have to purchase:

1 Gammator$^{TM}$ per building (or some other shielded strong source of gamma radiation)
1 Scaler per group
1 GM tube per group
1 Timer per group (it may be included as part of the scaler)
1 Calibrated Board
1 Set of discs labeled A, B, C, and D where:

A is a 0.1 μc source $^{210}$Po an alpha emitter

B is a 0.1 μc source $^{90}$Sr a beta emitter

C is a 1.0 μc source $^{60}$Co a gamma emitter

D is a non-radioactive blank disc that looks very much like the others
*1 Dosimeter per student (0-200mr)
*1 Dosimeter per group (0-200 r)
1 Film badge per student
1 knee length lab coat per student
A supply of X-ray film
*1 GM survey meter per 2 to 3 groups
*1 Dosimeter charger per 6 groups
Cesium-137/Barium-137M Minigenerator, 9 μc
Tim-113/Indium-113M Minigenerator, 9 μc
Strontium-90/Uttrium-90 Minigenerator, 0.09 μc
Carbon-14 (sodium carbonate) 50 μc
Phosphorous-32 10 μc/5ml

The suppliers for these materials that authors used are given at the end of the Teacher's Guide.

*These items may be obtained from your local Civil Defense Agency.

## SUGGESTIONS FOR LABORATORY ARRANGEMENT

Almost any laboratory may be used to perform the experiments. It should have sinks, tables, and electrical outlets.

It is important that the counting section (location of scalers and G-M tubes) be somewhat removed from where samples are being prepared and where radioactive materials are stored. If you have two rooms available, this is ideal. Many laboratories have an adjacent prep room and the prep room could possibly be used as the counting room. If you have to use one room then it will be best if you can keep your counting equipment in one area and your sample preparation and storage in the other.

Storage does not present a problem. The radioactive materials should be kept in one central place, preferably locked in a cabinet. Gamma emitters may be stored in small lead containers if they contribute too much to the background count.

If you want to be able to move the Gammator$^{\text{TM}}$, it is suggested that you place it on a pallet. The pallet will keep it up off the floor and make it much easier to move.

If feasible, have special locks placed on lab (with keys labeled "Do Not Duplicate"). Although not necessary for safety, this is good public relations, and at this writing, is part of our license requirement from AEC.

## DECONTAMINATION, DISPOSAL, AND SAFETY

### DECONTAMINATION

In order to obatin accurate experimental results, glassware and other apparatus must be properly decontaminated. In this text, only license-exempt quantities of isotopes are used and thus decontamination is not a problem from the health standpoint.

To decontaminate glassware one can follow a procedure such as the following:

(1) Wash the apparatus in a strong detergent solution. Rinse with plenty of running water. This will usually be sufficient.

If still contaminated:

(2) Soak for a few days in a chromic acid solution. This should be done in the hood because a contaminent such as carbon-14 in sodium carbonate will produce a gaseous product. Do not soak metals in this solution.

(3) Soak for about 24 hours in distilled water. Rinse.

(4) Soak in alcohol for about 30 minutes.

(5) Dry and monitor. If it is still contaminated repeat the process.

The metal planchets are difficult to clean and thus should be discarded. Whenever a lab is being performed in which liquid radioisotopes are being used, the work should be done on a tray with a disposable diaper liner. This should prevent any contamination of tabletops, floors, etc. However, if they should become contaminated the following procedure should be followed:

(1) While wearing plastic gloves, wipe up the spill with porous paper toweling (dispose of contaminated toweling in special waste container - described in next section.)

(2) Wash the area with plenty of detergent and hot water.

(3) Rinse.

(4) Repeat the steps until the count is normal.

If the contaminated area will not respond to this treatment, consult National Bureau of Standards Handbook 48.

If the students follow the procedures outlined in the text, nothing should ever become contaminated except glassware and other similar materials actually being used in the experiment.

## DISPOSAL

A large waste can, with a lid, lined with a disposable plastic bag, should be kept in the laboratory. This waste can should be used only for radioactive wastes. It should be marked with the radiation warning label. A plastic garbage can (yellow if possible) with a lid works very well.

Students should be instructed to use this can for disposal of contaminated solid wastes such as planchets, tray liners, etc.

Contaminated apparatus such as beakers, pipettes, etc. should be placed in a separate deep tray for teacher decontamination unless the experiment calls for the student to perform this task.

A large wide-mouth bottle, two to four quart size, should be kept in the laboratory for disposing of liquid radioactive wastes. This bottle should be labeled with the proper warning label.

The teacher should hold these wastes for as long a time as possible. This will allow as much decay as possible. When you have allowed as much decay as possible, the liquid waste can then be put down the sink, a little at a time, flushed down with large amounts of water. The longest half-life liquid isotope that is used in this course is phosphorous-32 which has a half-life of 14.3 days. If a radioactive substance can be retained for 7 half-lives, less than 1% of the original radioactivity will remain.

One sink in the lab should be designated as the "hot sink". This sink should be used for disposal of radioactive liquids. The sink should not be used for drinking purposes.

If you should accumulate greater than the exempt quantity of waste, consult Part 20 of the A.E.C. Rules and Regulations for the proper disposal procedure.

Solid wastes that contain long lived isotopes should be placed in sealed bottles and buried at least four feet beneath the surface of the ground. In this course, you should not have to be concerned with this procedure.

In summary, the basic principles of disposal are decay, dilution or burial.

## SAFETY

In this course, only license exempt quantities of radioisotopes are used. The radioactive chemicals at these low levels present no great radiation hazard. However, these chemicals should be handled with care and respect. Common sense, good housekeeping, and proper techniques are just as essential with sulfuric acid as they are with radioactive materials.

One must be careful that he does not contaminate the work area or the instruments. Thus it is essential to pre-plan each move and to have rules that must be followed.

It is good practice to have everyone (including the instructor) wear knee-length laboratory coats. If any radioactive liquids are spilled on the coat, the coat can be quickly removed. The coat can then be washed until it shows no activity.

The students should wear dosimeters while working in the laboratory. They should read and record their dosimeter readings each day in order to keep an accurate account of their radiation exposure record. It is good practice to have a film badge for each student and have it read monthly.

The following booklets should be obtained:

(1) NCRP Report No. 32 Radiation Protection in Educational Institutions

(2) NCRP Report No. 39 Basic Radiation Protection Criteria

These booklets may be obtained for $0.75 each from

NCRP Publications

P.O. Box 4867

Washington, D.C. 20008

## A.E.C. LICENSES

The only piece of equipment that you will need to license is the Gammator. The company from which you obtain the instrument will furnish you with the necessary information to obtain your license.

If you want to use more than license exempt quantities of radioisotopes it would be necessary for you to obtain a specific license from the A.E.C. Applications may be obtained from:

U.S. Atomic Energy Commission
Washington 25, D. C.
Attention: Isotopes Branch Division of Licensing
& Regulations

Your state may also require the registration of the Gammator. If you contact your State Board of Health you can obtain the necessary information.

## CHAPTER 1

### INTRODUCTION TO CHAPTER 1

Chapter 1 is a very brief chapter which introduces the student to the course and establishes certain daily record keeping procedures. From the beginning, the teacher should emphasize the importance of proper lab safety. An attitude of respect rather than fear of radiation should be developed.

### INTRODUCTION

This section can be read in class and should require little or no class discussion.

### EXPERIMENT 1-1 KEEPING A RECORD

The purpose of this experiment is to establish record keeping and safety procedures. The reading of the dosimeter as established in this lab will be used each time the student works with radioactive materials.

OBJECTIVES:

Given a film badge and dosimeter, the student must differentiate between them, charge a dosimeter, read the dosimeter, construct and use a data table of dosimeter readings, and adapt the table to a routine of daily readings throughout the course.

ESTIMATED TIME:

25 minutes including brief prelab. No postlab needed.

MATERIALS

- *1 0-200 mr dosimeter per student
- *1 film badge per student
- 1 dosimeter charger per class
- *1 laboratory coat per student

*These materials will be worn for the rest of the course.

ADVANCE PREPARATION:

Put the film badges together (Instructions will come with the film and film badges).

HINTS:

Treat dosimeter and film badge as a black box and don't get involved in a discussion of how they work. In later activities they will learn how they work. If only a limited number of dosimeters are available, a system whereby students check out their dosimeters at the beginning and the end of each period may be used.

PRELAB DISCUSSION:

The teacher should discuss the problems in charging a dosimeter such as what to do if the fibre goes off scale and disappears. (The teacher should try charging a dosimeter beforehand.)

POSTLAB:

No postlab needed.

* * * * * * * * * * * * * * *

The film Opportunity Unlimited could be shown here as an overview for the course.

## CHAPTER 2

### INTRODUCTION TO CHAPTER 2

In Chapter 2 the student discovers various methods of detecting radiation. In the process he also discovers that there are different types of radiation. Students are issued 4 discs labeled A, B, C, and D. They use photographic film, cloud chambers, electroscopes (dosimeters) and geiger counters to determine which discs are radioactive. They summarize their results and after being told the properties of alpha, beta, and gamma radiation, they are asked to determine which type of radiation (if any) each disc is emitting. Following this are some experiments which serve as checks on their "model".

The teacher should not mention the names alpha, beta, and gamma until Experiment 2-9 has been completed.

The teacher should remain in the background as much as possible as the student progresses through the chapter. Throughout the entire course the teacher should let the student discover. If the teacher observes that the student is having difficulty, hints can then be offered.

In addition to the major objectives of the experiments, Chapter 2 covers a time when students should be establishing good laboratory techniques and good techniques for recording their observations. They should also be establishing, as habit, such routines as recording their dosimeter readings. Frequent reminders, from the teacher, may be necessary until the routines are established as habit.

It should be noted that one of the Chapter 3 experiments must be started early in Chapter 2. Refer to the suggested schedule.

### EXPERIMENT 2-1 INVESTIGATION OF DISCS - ARE THEY THE SAME OR DIFFERENT?

The purpose of this experiment is to let the student discover that radioactivity cannot be detected by his senses but can be detected by photographic film.

#### OBJECTIVES:

Given four unknown discs and X-ray film packs, the student must observe that radiation cannot be detected by the senses, be able to develop X-ray film packs, observe which discs expose the film in the pack, and conclude that radiation from a source has the ability to penetrate materials that light cannot penetrate.

#### ESTIMATED TIME:

Prelab and placing discs on film - 10 minutes.

Completing the experiment (next day) - 45 minutes.

Postlab - 30 minutes.

### MATERIALS:

PER GROUP - 1 20ml syringe
4 discs labeled A, B, C, and D (see specials materials list)
1 X-ray film in light proof packet
Tape or grease pencil to mark X-ray packet
1 straight pin

PER CLASS - Developer solution (20ml per group)
Fixer solution (20ml per group)
Cellophane or masking tape

### ADVANCE PREPARATION:

See special materials section concerning discs.

Mix developer and fixer solution (follow manufacturers directions). See equipment list for source.

### HINTS:

Don't mention alpha, beta, or gamma radiation. The students will discover and identify the discs by the time they finish Chapter 2. Although it should not be mentioned at this point, the student will later find that Disc A is radioactive. If two classes are using the same discs, the overnight exposures may have to be done with 4 students per set.

### PRELAB DISCUSSION:

In order to get the students to follow directions, do not give any instructions other than the location of materials to be used and where they are to leave their disc/film packet arrangement for 24 hours.

### TYPICAL RESULTS:

Q1 - Can you use your sense of sight, touch, smell or hearing (DON'T TASTE!) to determine whether the 4 discs contain the same or different materials?

A1 - Students may answer no or yes. They may answer yes if the colors of the discs are different or if they have some other physical differences. (At this point either answer is acceptable.)

Students should record the code they use for identification of the disc placement on the film. Such as:
1 hole - A
2 holes - B
3 holes - C
4 holes - D

Q2 - Did any of the discs expose the film? Record the degree of exposure, if any, for each disc.

A2 - Yes. B was dark and distinct. C was dark and blurred. A & D did not expose the film.

Q3 - If your answer to Question 2 was yes, which ones exposed it?

A3 - B and C.

Q4 - If there was an exposure, was it caused by light?

A4 - No. If it was caused by light the whole film would have been exposed. The shape of the exposure was similar to the disc shape.

Q5 - Can you determine where any of the lettered discs were placed on the autoradiographs of other groups?

A5 - Yes. Other groups found that the same lettered discs exposed the film.

Q6 - Which discs do you think are radioactive?

A6 - B and C.

Q7 - Using your observations from this experiment, list as many properties of radioactivity as you can.

A7 - Exposes film
Goes through plastic (penetrate materials light cannot)
Senses cannot detect it.

Q8 - What further questions or experiments are suggested by your observations in this experiment?

A8 - Why did radioactive discs only show up on film?
By what other means can radiation be detected?
What was in the other disc that did not expose the film?
To what degree are B and C radioactive?
What good is radiation?

## POSTLAB

Unless students are expected to draw conclusions by using class data the carbon copies should be picked up before the postlab discussion. You may want to have each group record class results in answer to Question 3. These results can be used in answering the rest of the questions. You may want to spend some time in this first session going over how they should record data in their notebooks.

## EXPERIMENT 2-2: THE CLOUD CHAMBER

The purpose of this experiment is (1) to demonstrate the particulate nature of radiation, and (2) to see different effects from different radiation sources.

### OBJECTIVES:

Given a cloud chamber, the student must differentiate between track types, differentiate between discs which seem to emit as opposed to discs which do not, and compare the results of the cloud chamber and the film experiments.

### ESTIMATED TIME:

Prelab previous day - about 10 minutes.

45 minutes to perform the experiment

Postlab next day - about 30 minutes

### MATERIALS:

PER GROUP - cloud chamber
- disc set
- radioactive needle
- eye dropper
- dry ice
- flat bottom beaker
- flashlight

PER CLASS - isopropyl or methyl alcohol - about 50 ml
- heavy gloves or tongs to handle dry ice
- polaroid camera - optional

### ADVANCE PREPARATION:

Procure the dry ice. Small flat pieces work the best. Place dry ice slab at each station so the students don't have to handle it.

### HINTS:

Make sure the depression in the dish is toward the hole in the cloud chamber. Alpha will not pass through the plastic. You may have to help them locate the cloud layer in the chamber. Make sure dry ice is in flat pieces, a little larger than the cloud chamber's diameter.

### PRELAB:

Warn students about touching dry ice. Discuss the idea that a jet can leave vapor trail that one can see, yet he cannot see the plane. Approach the cloud chamber experiment with this idea.

### TYPICAL RESULTS:

Q1 - What do you observe? Describe and draw sketches of your observations in your lab notebook.

A1 - A. Tracks near disc wide and straight.

B. Tracks finer than A, shorter than A, not as straight as A.

C. Most groups - no tracks.

Q2 - If you see any tracks, do they all appear to be the same?

A2 - A. About the same, some longer, some thicker.

B. About the same.

(NOTE: If tracks are seen from discs C, D, or no disc, they are probably from cosmic radiation and could be from any direction.)

Q3 - If you see any tracks, do they all appear to be coming from the discs?

A3 - A. From the disc.

B. From the disc or not from the disc.

Q4 - Do you think individual particles are coming from any of the sources?

A4 - Yes. A & B.

Q5 - Which discs appear to be radioactive on the basis of this experiment?

A5 - Yes. A & B.

Q6 - Does your answer to Q5 agree with your predictions based upon the film exposure in Experiment 2-1?

A6 - No. In the film experiment Disc C appeared to be radioactive and Disc A did not. In this experiment the reverse was true. The prediction regarding Disc B appeared correct.

Q7 - Do you observe any tracks which appear to be coming from the needle?

A7 - Yes.

Q8 - If so, do the tracks appear similar to those from any of the discs?

A8 - Generally A, occasionally B.

Q9 - What further questions or experiments are suggested by your observations in this experiment?

A9 - See what made certain trails from discs?

Why A didn't show on the film?

Is D radioactive?

Why C had no tracks but exposed the film?

Why tracks shot out at intervals?

POSTLAB:

Make a class data chart on the board and have each group report their observations while you record. A sample follows:

OBSERVATIONS

Disc A

Disc B

Disc C

Disc D

No discs or needles

Needle

After summarizing the observations, have the student finish answering the questions.

TEXT MATERIAL - PAGES 12 & 13:

A more complete atomic model will be developed in Chapter 5. The purpose at this point is to introduce ionization, therefore, the atomic model should not be elaborated upon.

## EXPERIMENT 2-3: THE ELECTROSCOPE, A CLASS EXPERIMENT

The purpose of this experiment is to show that radiation will discharge an electroscope, and show possible differences in the discharging rate from different radioactive sources.

### OBJECTIVES:

Given a demonstration electroscope system, the student must determine which discs affect the electroscope and differentiate the degree that each disc affects the electroscope.

### ESTIMATED TIME:

Since this is a demonstration, no separate prelab is needed. 45 minutes needed. No postlab is needed as data will be tabulated as the experiment is performed.

### MATERIALS:

PER CLASS - 1 demonstration electroscope
1 overhead projector (for horizontal projection) or slide projector
1 set of discs
1 felt pen
1 large white sheet of paper
1 piece of fur
1 hard rubber rod

### ADVANCE PREPARATION:

Try it to see how long it takes to get a measureable discharge Attach wire to electroscope knob as shown in the text.

### HINTS:

Electroscope may be more easily charged by touching wire attached to electroscope knob. The electroscope must have high sensitivity.

### PRELAB:

None

## TYPICAL RESULTS:

Q1 - What do you observe?

A1 - The leaf moves away from the fixed rod. (The leaves separate).

Q2 - Why did the electroscope leaves separate when the knob was touched with the charged rod?

A2 - Both leaves (the rod and the leaf) have the same charge. Like charges repel.

Q3 - Did the position change?

A3 - Yes, the leaves moved down - but only slightly.

Q4 - Did the change, if any, indicate a charging or discharging effect on the electroscope?

A4 - Discharging.

Q5 - Did the position change? If so, how did this change compare with Part 2?

A5 - The change was in the same direction, but much greater.

Q6 - Did the change, if any, indicate a charging or discharging effect on the electroscope?

A6 - Discharging.

Q7 - Did the position change? If so, how did this change compare with Part 2? Part 3?

A7 - The Part 4 change was greater than Part 2, but less than Part 3.

Q8 - Did the change, if any, indicate a charging or discharging effect on the electroscope?

A8 - Discharging.

Q9 - Did the position change? If so, compare the change with Part 2, Part 3, and Part 4.

A9 - The change was about the same as Part 2 - less than Part 3 and Part 4.

Q10 - Did the change, if any, indicate a charging or discharging effect on the electroscope?

A10 - Discharging.

Q11 - In each of the parts, did the movement of the leaves indicate a charging or discharging effect on the electroscope?

A11 - Discharging.

Q12 - In which part(s) did the largest discharging effect occur?

A12 - The largest discharge occurred in Part 3 with Disc A.

Q13 - Which discs do you think produced the greatest number of charges?

A13 - Disc A seems to produce the greatest number of charges because it caused the electroscope leaves to fall the fastest.

### TYPICAL RESULTS:

| PART | DISC | TIME | DISTANCE MOVED |
|---|---|---|---|
| 2 | None | | |
| 3 | A | | |
| 4 | B | | |
| 5 | C | | |
| 6 | D | | |

### TEXT MATERIAL - PAGES 16-18:

A brief discussion comparing the electroscope and the dosimeter is appropriate. Make sure the students realize the dosimeter is an electroscope.

### EXPERIMENT 2-4: THE DOSIMETER

The purpose of this experiment is to acquaint the students with the use of a dosimeter (miniature electroscope) as a radiation detection instrument. They also determine the radiation dose produced by the Gammator.

### OBJECTIVES:

Given two types of dosimeters, dosimeter charger, discs, and Gammator, the student must differentiate between the effects on the dosimeter from different sources of radiation.

### ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 30 minutes

Postlab - 15 minutes

## MATERIALS:

PER GROUP - 1 set of discs
1 dosimeter (0-200 r)
1 dosimeter (0-200 mr)

PER CLASS - 1 dosimeter charger
1 Gammator

## ADVANCE PREPARATION:

None.

## HINTS:

The 10 to 20 second time interval in the Gammator should be started when the handle of the Gammator hits the handle stop. At the end of the interval, they should quickly open Gammator chamber.

## PRELAB:

Tie the preceding text in with this lab. Demonstrate how to open and close the Gammator.

## TYPICAL RESULTS:

PART I - Dosimeters clipped with disc for 10 minutes.

Q1 - Did the dosimeter reading change? If so, how much?

| | | 0-200 mr | 0-200 r |
|---|---|---|---|
| A1 - | A | No change | No change |
| | B | No change | No change |
| | C | No change | No change |
| | D | No change | No change |

PART II

Q2 - In what units are the scales calibrated?

A2 - Roentgens or milliroentgens

Q3 - What is the change in readings?

A3 - (a) - 1-2 second exposure in Gammator
0-200 mr fibre off scale
0-200 r 10 to 15 r (with our source)

(b) - 10 second exposure of 0-200 r dosimeter in Gammator about 80-90 (with our source).

Q4 - If you left the dosimeters in the Gammator for 1 hour, how many roentgens would they read, assuming the scale would go to any value?

A4 - About 30,000 r (our source).

### POSTLAB:

Compare results - especially Question 4. (Obtain a "class" value - compare with manufacturer's value and use this value for later experiments).

## TEXT MATERIAL ON PAGES 21-23:

Discuss the text material on pages 21 and 22 and have the students work Exercise 2-1. Check exercise. Discuss text material on page 22 after exercise 2-1. Have students work Exercises 2-2 and 2-3. Check exercises.

Discuss text material on page 23.

2-1 (a) $\frac{2.08 \times 10^9 \text{ ion pairs}}{1\cancel{r}} \times 0.5\cancel{r} = \underline{1.04 \times 10^9 \text{ ion pairs}}$

(b) $\underline{0.5\text{r}}$

2-2 (a) $0.0005\cancel{r} \times \frac{1000\text{mr}}{\cancel{r}} = \underline{0.5 \text{ mr}}$

(b) $5000\cancel{\text{mr}} \times \frac{1 \text{ r}}{1000\cancel{\text{mr}}} = \underline{5\text{r}}$

(c) $\underline{1\text{r}}$

2-3 (a) $\underline{10\text{r/hour}}$

(b) 10r/5 hours = $\underline{2\text{r/hour}}$

(c) 10r/0.5 hour = $\underline{20\text{r/hour}}$

(d) $\underline{\text{c}}$

## EXPERIMENT 2-5: SCALER/COUNTER

The purpose of this experiment is to introduce the students to the use of scaler.

### OBJECTIVES:

Given a scaler, the student must be able to use the controls correctly, and demonstrate what stimulus is necessary to make the scaler operate.

ESTIMATED TIME:

Prelab - 5 to 10 minutes

Experiment - 40 minutes

Postlab - 10 minutes

MATERIALS:

PER GROUP - 1 scaler
1 bell switch
1 battery 1½ volts
Hook-up wire

ADVANCE PREPARATION:

Prepare cards for all control settings and attach cards to scalers. See sample card:

NUCLEAR/CHICAGO

| CONTROL | Setting with Bell Switch | With GM tube |
|---|---|---|
| High Voltage | Off | On |
| HV Adjust | 450 V | Marked on GM tube |
| Test/use | Use | Use |
| Count Stop | Count | Count |
| Master | On | On |

HINTS:

Make sure the high voltage of the scaler is turned off. Suggest students tap the bell switch to answer Question 1.

You can't use a power supply in place of the 1½ volt battery because the pulsating direct current will trigger the scaler.

PRELAB:

Emphasize that they should follow directions very carefully.

**TYPICAL RESULTS:**

Q1 - Can you cause the recorded count to advance one at a time by operating the bell switch?

A1 - Yes, some groups could tap switch to advance one count at a time. No, others get 2 or 3 count advance.

Q2 - Press the reset switch. What happens?

A2 - Resets scale back to zero.

Q3 - Move the count on-off switch to the OFF position and then try to advance the count by operating the bell switch. What do you think is the purpose of the count on-off switch?

A3 - Stops the count.

Q4 - What happens to the recorded count when the count on-off switch is operated several times?

A4 - Stops the count, turns count on.

Q5 - What number is recorded on the scaler?

A5 - About 3600.

Q6 - Within what percent are these readings the same?

A6 - Zero or near zero.

Q7 - What is the average number of counts per second?

A7 - Very near 60.

Q8 - We are using 60 cycle per second alternating current. What do you think you have measured in the above trial?

A8 - Cycles of electric current.

**POSTLAB:**

Compare results especially Questions 7 and 8.

## EXPERIMENT 2-6: SCALER WITH G-M DETECTOR

The purpose of the experiment is to introduce the G-M tube with a scaler as a means of detecting radiation, to determine which discs are radioactive, and to use shielding to determine penetration of radiation from discs.

## OBJECTIVES:

Given a scaler, a variety of shields and four source discs, the student must accurately measure background count, differentiate between the penetrating capabilities of each source disc as demonstrated by the various shields, list the most effective shield for protection from the type of radiation of each disc.

## ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 45 minutes

Postlab - 20 minutes

## MATERIALS:

PER GROUP - Scaler
- G-M tube
- Set of discs
- Timer
- Aluminum Shield
- Lead Shield
- Piece of paper (shield)
- Calibrated Board
- Disc holder

## ADVANCE PREPARATION:

Mark operating voltage on each G-M tube.

## HINTS:

Suggest students complete all trials with disc A, then disc B, etc. This will prevent changes in geometry as the student uses these different shields.

## PRELAB:

Warn students about the thin end window on the G-M tube and make sure they set their voltage to that assigned to the G-M tube.

## TYPICAL RESULTS:

Part I:

Q1 - What is the recorded count after 2 minutes?

A1 - Between 35 and 50.

Q2 - What would this be in counts per minute?

A2 - Between 18 and 25.

Q3 - What is the average background, in counts per minute, for these trials?

A3 - Between 18 and 25.

Part II:

FIGURE 2-17 - TYPICAL CORRECTED COUNTS:
Disc

| Shield | A | B | C | D |
|---|---|---|---|---|
| None | 2250 | 11876 | 4783 | 0 |
| Paper | 0 | 10680 | 4746 | 0 |
| Aluminum | 0 | 9321 | 4595 | 0 |
| Lead | 0 | 12 | 3889 | 0 |

Some of the "0" values might be negative numbers or very small values until they realize the background count is random. (This will be clarified in the next experiment).

Q4 - For which unshielded sample was the count the greatest?

A4 - B

Q5 - For which unshielded sample was the count the smallest?

A5 - D

Q6 - What conclusion do you draw from these results?

A6 - B radioactive - D isn't.

Q7 - From which disc do you consider the radiation most penetrating?

A7 - C

Q8 - From which disc do you consider the radiation least penetrating?

A8 - A (D is also a possible answer).

Q9 - What leads you to this conclusion?

A9 - A had small counts for all shields.

C counts didn't change for the lead shield as much as B.

Q10 - Radioactive materials are used on luminous watch hands. Which radiation would you consider the safest for use on a watch hand?

A10 - A (D acceptable if they still think it may be radioactive).

Q11 - What material would be required in clothing to protect an experimenter from the radiation of Sample A? Explain your decision.

A11 - Regular clothing, paper, etc. This radiation didn't penetrate paper.

Q12 - What material would be needed for protection from Sample B? Explain.

A12 - Lead - aluminum didn't reduce the count very much.

Q13 - What material would be needed for protection from Sample C? Explain.

A13 - Even the sheet of lead didn't provide much protection.

Q14 - What material would be needed for protection from Sample D? Explain.

A14 - Not radioactive - don't need anything special.

Q15 - Recalling the effect of the bell switch on the scaler, what do you think happens when radiation enters the G-M tube?

A15 - Causes electrical impulse.

Q16 - Could radiation be detected with the scaler alone?

A16 - No.

## POSTLAB:

Post a chart on the board similar to Figure 2-17 and have each group record their results. Many students will record negative numbers. Postpone any detailed discussion of this until they complete the next experiment.

## EXPERIMENT 2-7: COUNTING STATISTICS

The purpose of this experiment is to make the student aware that small differences in radiation counts (because of random fluctuations in radiation) may not be significant.

### OBJECTIVES:

Given a series of recorded counts, the student should recognize significant differences when they occur.

## ESTIMATED TIME:

Prelab - 5 minutes

Experiment - 30 minutes

Postlab - 10 minutes

## MATERIALS:

PER GROUP - 1 G-M tube & scaler
1 Calibrated Board
1 Disc holder
1 Disc C

## ADVANCE PREPARATION:

None.

## HINTS:

None.

## PRELAB:

Refer to data from Experiment 2-6, particularly where negative values were obtained for the corrected count. Discuss possible random variation of counts.

## TYPICAL RESULTS:

The answers to Q2 through Q7 will depend on sample activity, geometry, randomness of activity and background. Those shown were taken from the notes of one of our students.

Q1 - Would you expect to obtain the same value if you took another 1 minute count?

A1 - The student might answer either yes or no - either answer is okay at this point.

Q2 - What is the average counts per minute?

A2 - 29

Q3 - What is the maximum amount that any of your 1 minute counts varied from the average?

A3 - 8 counts/min.

Q4 - What percent is this variation of the average count?

A4 - 40%

Q5 - What is the average counts per minute?

A5 - 3137

Q6 - What is the maximum amount that any of your 1 minute counts varied from the average?

A6 - 79

Q7 - What percent is the variation of the average count?

A7 - 2.5%

Q8 - As the count rate increases does the percent variation change significantly? (Compare Q4 & Q7)

A8 - At the high count rate the percent variation is smaller.

Q9 - Source #1 shows an activity of 500 c/m when placed in front of a G-M tube. If source #2 were placed in the same position, how large a 1 minute count would you have to obtain before you could be fairly certain that source #2 is stronger than source #1?

A9 - Answer will depend on the answer to question 8. (Probably about 550 c/m)

### POSTLAB:

Compare answers (particularly Q7 & Q8) Try, through class discussion, to arrive at some general ideas to follow in determining if a particular variation is significant. Refer to text material on pages 30 and 31 during postlab discussion.

### ANSWERS TO EXERCISES:

2-4. (a) No, No, Yes

(b) Thinner

(c) The same or greater

(d) Keep gas inside

(e) Worthless

2-5. (a) 250, 1000

(b) B counts twice as long as A

Report as counts/minute (c/m)

NOTE: CHECK DAILY SCHEDULE CONCERNING START OF EXPERIMENT 3-4

## EXPERIMENT 2-8: VOLTAGE AND THE GEIGER-MULLER TUBE

The purpose of this experiment is to find out (1) why there is a particular voltage for their G-M tube and (2) why the voltage cannot be changed during an experiment.

### OBJECTIVES:

Given a scaler, G-M tube and disc C, the student must identify, for the particular G-M tube he is using, the: (a) starting potential, (b) plateau, (c) threshold, (d) continuous discharge region, (e) proportional region, (f) proper operating voltage, and (g) possible ill effect of high voltage on G-M tube.

### ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 40 minutes

Postlab - 30 minutes

### MATERIALS:

PER GROUP - 1 G-M tube
1 Scaler
1 Timer
1 Disc
1 Calibrated board
1 Disc holder

### ADVANCE PREPARATION:

None.

### HINTS:

If you use several different G-M tubes, you may find quite a different range of plateaus. Step B - only reason for this is to make sure they do not get too high a voltage.

### PRELAB:

Discuss the technique used to determine the continuous discharge voltage. Make sure they turn up the voltage slowly until they get a count of 100 c/m or so without a radioactive source present. Operation at too high a voltage for an

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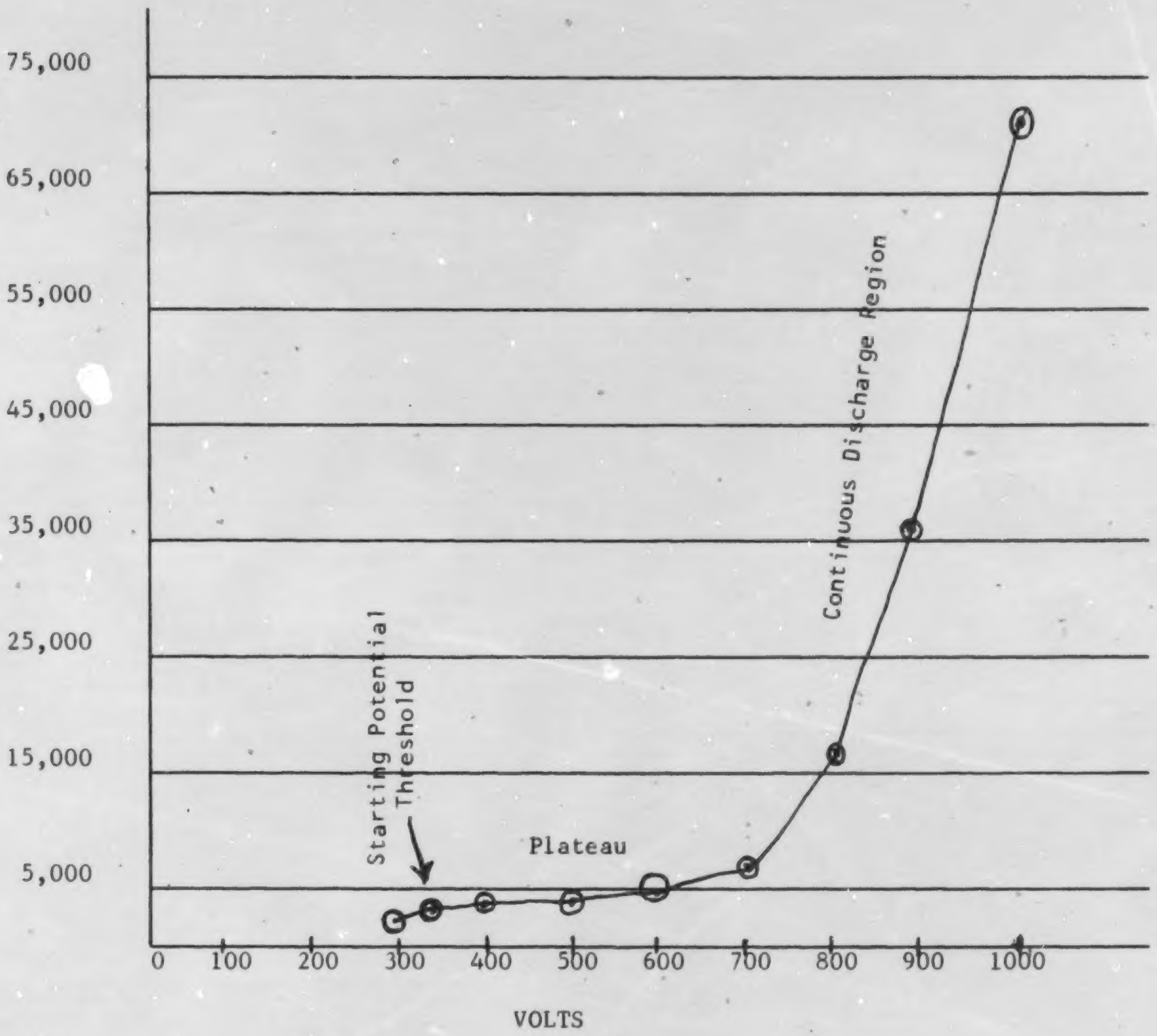
extended period of time will damage the G-M tube. Make sure the disc and tube stay in the same position during the entire experiment.

TYPICAL RESULTS:

VOLTAGE VS COUNTS PER MINUTE



Q1 - Indicate on your graph the voltage at which the detector first began to detect radiation. This is called the "starting potential".

A1 - 325 volts (our tube). Answers will vary greatly.

Q2 - Observe your graph. Draw dotted lines from the curve to the voltage axis indicating the area where the count rate did not change significantly with a voltage increase. This is called the "plateau".

A2 - 400 to 600 volts.

Q3 - Indicate on your graph the voltage where the "plateau" begins. This is called the "threshold" of the detector.

A3 - 350 volts.

Q4 - Indicate on your graph the voltage where a slight increase in the voltage caused a large increase in the count rate. This is the beginning of the "continuous discharge region"

A4 - 700 to 800 volts.

Q5 - The proper operating voltage for the G-M tube is a value which is approximately one third of the way through the plateau Does the voltage previously assigned to this tube fall within this range?

A5 - Yes, tube assigned 450 volts.

Q6 - When you are using the G-M detector, should the voltage be changed during an experiment? Explain

A6 - No, since increasing voltage increases count.

Q7 - When the voltage setting of the G-M tube is below the plateau, it is said to be in the "proportional region". What difficulties could you encounter if you tried to detect radiation in this region?

A7 - Small voltage change causes a significant change in count.
Less sensitive to radiation.

POSTLAB:

Compare graphs by making a blackboard sketch of the different types of plateaus. This shows the different tube characteristics. For the purpose of this course it is not necessary to explain why the plateaus exist. Might tabulate for all groups; threshold, continuous discharge, length of plateau, operating voltage.

## EXPERIMENT 2-9: ALPHA, BETA, AND GAMMA RADIATION OR WHAT'S IN A NAME?

The purpose of this experiment is to summarize the characteristic properties of the radioactive samples and to assign names to the radiations when given information about alpha, beta, and gamma radiation.

OBJECTIVES:

Given the results of previous experiments and the characteristics of alpha, beta, gamma radiation, the student must correctly identify each disc as to the type of radiation it emits.

ESTIMATED TIME:

Prelab - very brief

Experiment - 25 minutes

Postlab - 15 minutes

MATERIALS:

Results of previous experiments.

ADVANCE PREPARATION:

None.

PRELAB:

Make sure they follow directions.

TYPICAL RESULTS:

Summary of results from previous experiments:

| PROPERTIES | A | B | C | D |
|---|---|---|---|---|
| Exposed film | No | Yes | Yes | No |
| Trails in cloud chamber | Yes | Yes | No | No |
| Electroscope Discharge | Yes | Yes | No | No |
| Dosimeter Discharge | No | No | No | No |
| G-M count | Yes | Yes | Yes | No |
| Shielded by | Paper | Lead | Lead | (to some extent) |
| Radioactive | Yes | Yes | Yes | No |

Q1 - Which of the discs are radioactive?

A1 - A, B, C.

Q2 - Which radioactive disc contains the most penetrating source of radioactivity? Which the least penetrating?

A2 - C, A (shielding).

Q3 - Which of the radioactive sources seem to emit particles? Is there any radioactive source that does not seem to emit particles?

A3 - A, B (cloud chamber). Possibly C does not.

Q4 - If any of the discs do give off particles, which do you think emits the largest particles?

A4 - A (cloud chamber).

Q5 - Which of the radiations appear to have an electrical charge?

A5 - A, B (electroscope).

Q6 - If any of the radiations appear to have an electrical charge, which has the greatest?

A6 - A (discharged electroscope at greatest rate) (largest cloud chamber track).

Q7 - Why do you think Disc A did not expose the film?

A7 - Radiation did not penetrate plastic covering.

Q8 - Using the summary table above for the three common types of radiation, which radiation was Disc A producing? Disc B? Disc C? Disc D?

A8 - A - alpha
B - beta
C - gamma
D - none

Q9 - What kind of radiation do you think the Gammator emits?

A9 - Gamma

POSTLAB:

Check over their results as they hand them in. If necessary, you may have to compile a class summary of properties so that each student assigns the discs properly.

## EXPERIMENT 2-10: MAGNETIC FIELDS AND RADIATION

The purpose of this experiment is to (1) test the effect of magnetic fields on radiation and (2) to test the model that beta radiation consists of charged particles.

OBJECTIVES:

Given discs B and C, scaler, G-M tube, lead shield, and horseshoe magnets, the student must identify whether either or both beta and gamma radiation consist of charged particles that bend in a magnetic field and from alpha radiation characteristics write reasons why an alpha source would not be practical to use in this experiment.

## ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 45 minutes

Postlab - 15 minutes

## MATERIALS:

PER GROUP - 1 Disc B
1 Disc C
4 lead shields
1 G-M tube
1 Scaler
1 Timer
3 Horseshoe Magnets
1 Calibrated board
1 Millimeter ruler
Masking tape

## ADVANCE PREPARATIONS:

Strong magnets are needed; you'd better check yours before trying this experiment.

## HINTS:

If horseshoe magnets are used, make sure magnets are in the same place for each trial.

## PRELAB:

Briefly discuss the text material preceding the experiment. Make sure that they work with the beta source first and answer the questions pertaining to it before they do the same with the gamma source.

## TYPICAL RESULTS:

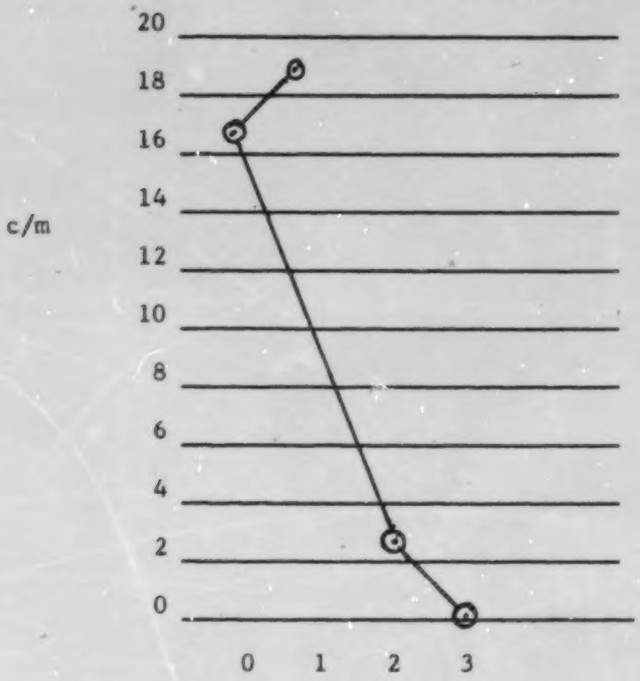
Part I

Q1 - Is there evidence that the magnets, or more properly the magnetic field of the magnets, affects the beta particles?

A1 - Yes.

Q2 - What, if anything, happened to the particles?

A2 - Particles bent so they did not hit the G-M tube.



Q3 - Describe and explain the shape of your graph.

A3 - As more magnets are used less radiation is detected by the tube. As more magnets are used, the particles are bent more.

Q4 - Can the graph indicate the amount of magnetism of the individual magnets?

A4 - No.

Part II

Q5 - Is there any evidence that the magnets affect gamma rays?

A5 - No (they may plot their data for Disc C also - it will show a random fluctuation).

Q6 - Is a beta particle charged?

A6 - Yes.

Q7 - Is a gamma ray charged?

A7 - No.

Q8 - Would a magnetic field bend an alpha particle?

A8 - Yes.

Q9 - Would it be practical to use an alpha source in this experiment? Explain.

A9 - No, they do not travel far enough to be detected in this experiment.

POSTLAB:

If student results vary considerably draw a composite graph on the blackboard so students can compare results before they answer the question.

LAB TEST FOR CHAPTER II:

The purpose of this lab test is to have the students use lab techniques used thus far to identify radiation(s) given off by an unknown sample. The student has to plan his own techniques, procedures, and record his date.

ESTIMATED TIME:

1 to 2 periods.

MATERIALS:

PER GROUP - all materials used thus far should be available
upon their request
1 unknown

ADVANCE PREPARATION:

Unknowns will have to be made up in advance. You can use solid sealed sources that you can purchase. Make sure any indication of the type of radiation emitted is removed. You can also use liquid sources and put a couple drops in a planchet. Evaporate the sample under a heat lamp and cover. Most chemistry labs will have uranium acetate or uranium nitrate and a small amount of this could be put in a planchet. Make sure that you get about 1,000 c/m from the sample when it is about 2 cm from the G-M tube.

Examples that were used in the trial:

| Disc | Material | Type of radiation |
|---|---|---|
| A | $Ra^{278}$ | $\alpha$ |
| B | $Sr^{90}$ | $\beta$ |
| C | Uranium Acetate (The $\alpha$ emitted was shielded by planchet cover) | $\beta$ |
| D | $Zn^{65}$ | $\beta, \gamma$ |

| | | |
|---|---|---|
| E | $Ce^{144} + Zn^{65}$ | $\beta, \gamma$ |
| F | $Ce^{144}$ | $\beta$ |
| G | Blank planchet. | nothing |

HINTS:

Some groups will finish in a 40 or 45 minute period, but others will need more time. One can let these groups work on their unknowns during waiting time in the next two experiments.

PRELAB TEST DISCUSSION:

Emphasize that they are to plan their own procedures and they can use any techniques learned thus far. Mention that they should start with simple techniques first before they use the more elaborate set-ups. (They don't need to use the photo film or cloud chamber to do this test.)

POSTLAB TEST DISCUSSION

After correcting the tests give the students an opportunity to ask about any mistakes they might have made. No formal class discussion is necessary.

## EXPERIMENT 2-11: SOLUTION CONDUCTIVITY

The purpose of this experiment is to show that the conductivity of water can be affected by the amount and type of material dissolved.

OBJECTIVES:

Given conductivity testing equipment and various materials to be dissolved in water, the student is to discover that conductivity is affected by the type and amount of material dissolved.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 45 minutes

Postlab - 10 minutes

MATERIALS:

PER GROUP - Small samples of sugar, alcohol, salt (NaCl)
Copper sulfate, and distilled water
Wash bottle
Conductivity vial

PER CLASS - A.C. Milliammeter (0-25 ma)

Power Supply (0-5 volts A.C.)

Potentiometer

Conductivity stopper

Hook-up wire

ADVANCE PREPARATION:

Assemble and test the conductivity circuit. (See special materials section)

HINTS:

The measuring process can be speeded up if more than one conductivity circuit is set up. If more than one circuit is used, make certain that students do not change from one circuit to another during the experiment.

PRELAB DISCUSSION:

Demonstrate conductivity tester. Remind student to rinse both the vial and the electrodes in distilled water between successive measurements. Emphasize that the power supply and potentiometer settings must not be changed throughout the experiment.

TYPICAL RESULTS:

Q1 - Did the reading on the milliammeter change? If so, how much?

A1 - No.

Q2 - How did this solution's conductivity compare with that of sugar?

A2 - The same (no conductivity).

Q3 - How much did the conductivity change?

A3 - It changed a lot. The conductivity went up quite a bit.

Q4 - How does this solution's conductivity compare with that of sugar? Of alcohol?

A4 - Much greater than either sugar or alcohol.

Q5 - How much did the conductivity change?

A5 - It changed more than any other trial.

Q6 - How does this solution's conductivity compare with that of sugar? Of alcohol? Of copper sulfate?

A6 - Much greater than either sugar or alcohol and a little greater than copper sulfate.

Q7 - How is the conductivity related to the number of grains of salt?

| No. of Grains | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Meter Reading | 0.11 | 0.52 | 1.25 | 1.52 | 2.60 |

A7 - As the number of grains of salt increases, so does the conductivity.

POSTLAB DISCUSSION:

Compare student results. Point out that the experiment is only semi-quantitative and we are concerned only with relative comparisons. Raise the question of why some solutions conduct electricity better than others. Then have the students read page 44 and do Exercise 2-6 page 45.

ANSWERS TO EXERCISES

2-6. (a) The model suggests that the sugar molecules did not break up into ions.

(b) As the amount of salt was increased, the number of ions in the solution increased. This resulted in an increase of solution current.

## EXPERIMENT 2-12: IRRADIATED SOLUTIONS

The purpose of this experiment is to show that radiation can produce ionization in a solution. Some solutions change color upon irradiation and can be used as dosimeters

OBJECTIVES:

Given a chemical solution and a radiation source, the student must identify by color change and by conductivity, whether radiation can affect the ionization of the solution and compare the conductivity change as the solution is irradiated for a longer time.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 40-45 minutes

Postlab - 15 minutes

**MATERIALS:**

PER GROUP - 1 Conductivity vial

PER CLASS - 1 AC milliammeter 0-25 ma
- 1 power supply 0-5 volt AC
- 1 Potentiometer
- 1 Conductivity stopper
- Hook-up wires
- 250 ml Ferric chloride solution
- 250 ml Ferrous chloride solution
- 50 ml 3% Hydrogen peroxide
- Wash bottle
- Gammator

**ADVANCE PREPARATION:**

The iron solutions are made using 5 grams per liter. The ferrous chloride solution should be made up the same day it is to be used.

**HINTS:**

See hints for Experiment 2-11.

**PRELAB DISCUSSION:**

Discuss text material on pages 45 and 46. Use this to lead into the experiment.

**TYPICAL RESULTS:**

Part I

Q1 - Describe the color of the ferric chloride.

A1 - Yellow.

Q2 - Describe the color of the ferrous chloride.

A2 - Greenish or clear.

Q3 - Was the conductivity affected by the radiation?

A3 - Yes.

Q4 - Did the color of the sample change?

A4 - Yes, clear or greenish to yellow.

Q5 - How does the final color of the sample compare with that of the reference solution? (Ferric chloride).

A5 - Sample appears to be turning the same color as the reference solution.

Q6 - Can we accept this as evidence of ionization by gamma radiation?

A6 - Since $Fe^{3+}$ is yellow and $Fe^{2+}$ is clear, it appears to be ionized.

Q7 - List 3 bits of evidence that radiation will cause ionization.

A7 - Cloud chamber, electroscope, conductivity of solution increased.

Part II:

Q8 - When hydrogen peroxide was added, did the solution's color change?

A8 - Yes, to yellow.

Q9 - If so, was the color change the same as for the irradiated sample?

A9 - Yes, both yellowish.

Q10 - Did the conductivity change in a way similar to that of the irradiated sample?

A10 - Yes.

Q11 - How could you use a solution of ferrous chloride to detect radiation?

A11 - If solution changes to yellow it would indicate radiation providing other variables were constant.

POSTLAB DISCUSSION:

Compile student results so these are available to the students for answering the questions.

## INTRODUCTION TO CHAPTER 3

Chapter 3 deals with the effects of radiation on both nonliving and living materials. The student discovers that exposure to natural radiation does not make a substance radioactive and then he explores sources of radiation in his environment.

Through the use of three or four experiments plus a "dry lab" the student discovers that massive doses of radiation can be fatal and that smaller doses can produce effects on both the individual (somatic effects) and on future generations (genetic effects).

In preparation for a lab to show the active uptake of a radioactive element by an organism, the safe handling of radioactive liquids is explored.

Finally, the different dangers involved in radiation exposure from internal and external radiation sources is investigated.

Scheduling of Chapter 3 is more difficult than in any other chapter because of the growth time of living materials. Experiments will overlap and several will be in progress at once. It is suggested that the teacher study the suggested schedule rather carefully. Changes can be made, of course, but since one change can effect several other experiments, it is suggested that a tentative schedule be mapped out before the chapter is begun.

### EXPERIMENT 3-1: IRRADIATION OF NONRADIOACTIVE MATERIALS

The purpose of this experiment is to show that exposure to radiation from radioactive substances does not make an object radioactive. See hints.

OBJECTIVES:

Given a Gammator and a variety of materials, the student will compare the radioactivity of the materials before and after a massive radiation dose to determine whether high irradiation causes the materials to become radioactive.

ESTIMATED TIME:

Prelab - 5 minutes

Experiment - 15 minutes in 2 successive days

Postlab - 10-15 minutes

MATERIALS:

PER GROUP - End window G-M tube
- Scaler
- Disposable plastic gloves

PER CLASS - Samples of each of the following:
- Living organic (seeds, nuts, etc.)
- Dead organic (wood, cork, etc.)
- Mineral (salt, stone, etc.)
- Liquid (water, alcohol, etc.)
- Metal (lead, aluminum, etc.)
- Disc D
- Gammator

ADVANCE PREPARATION:

None.

HINTS:

You should be careful not to imply that radiation can never produce radioactivity. High energy radiation such as that from particle accelerators can produce radioactivity. Very energetic particles and neutrons can alter the nucleus making the substance radioactive. Naturally occurring radiation will not induce radioactivity.

PRELAB DISCUSSION:

Mention that each group will use a different sample and they will "pool" their data.

TYPICAL RESULTS:

| Materials in Gammator 72 hours | Corrected Count Before Irradiation (c/m) | Corrected Count After Irradiation (c/m) |
|---|---|---|
| Seeds | 0 | 0 |
| Wood | 0 | 0 |
| Stone | 0 | 0 |
| Water | 0 | 0 |
| Metal | 0 | 0 |
| Disc D | 0 | 0 |
| Sand | 0 | 0 |
| Metal | 0 | 0 |

Q1 - Are any of the samples initially radioactive?

A1 - No.

Q2 - Have any or all of the samples become radioactive?

A2 - No.

Q3 - Was it necessary to handle these materials with plastic gloves?

A3 - No.

Q4 - What is the difference, if any, between food which has been irradiated with a radioactive material and food which has been contaminated with a radioactive material?

A4 - Irradiated food would not be radioactive, but contaminated food would be.

Q5 - If a person eats food which has been irradiated, will he be taking radioactive material into his body?

A5 - No.

POSTLAB DISCUSSION:

Use the blackboard to pool the students' results. The students will use these results to answer the questions.

EXPERIMENT 3-2: RADIATION IN OUR ENVIRONMENT

The purpose of this experiment is to make the student aware that radiation is everywhere in his environment.

OBJECTIVES:

Given a scaler, dosimeter, vacuum cleaner, and filter paper, the student will examine the amount of radiation in our environment; and, from the results of this examination, determine whether we can ever be free from some radiation, whether altitude has an increasing or decreasing effect on radiation, whether radiation is found on particles in the air, and whether we can effectively shield ourselves from all radiation.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 60 minutes

Postlab - 40 minutes

MATERIALS:

PER GROUP - G-M tube
Scaler
Mr dosimeter

PER CLASS - 4 or 5 portable G-M survey meters
1 dosimeter charger
Enough lead shields or bricks to make two set-ups as shown in Figure 3-1
1 high volume air sampler or vacuum cleaner (tank type)
Filter paper
Screen wire to fit over hole in vacuum cleaner, if used

ADVANCE PREPARATION:

After the students have taken their count on the filter paper, the teacher should start the air sampler (vacuum cleaner) about 4 hours before they are to count the paper. The teacher should have 3 or 4 set-ups as shown in Figure 3-1.

HINTS:

Time schedule is very important. The first period do the prelab, do all of Part I, issue dosimeters for them to set up Part II. Also the students can take the initial count of filter paper for Part III. The next day Part III can be completed. After one week when the dosimeters are read for Part II, the entire experiment can be discussed.

The filters should be cut up and each group given a piece to count for Part III immediately after being removed from the air sampler. The radioactive material collected has a short half-life.

PRELAB DISCUSSION:

Clarify procedure in Part I that part of the students will be checking various parts of the building while the others are using the set-up shown in Figure 3-1. They exchange places part way through the period. Point out that they are also to do the initial steps in Part II and III during this period.

TYPICAL RESULTS:

Part I:

Taking counts with portable G-M tube at various parts of the building:

| Location | C/M |
|---|---|
| Basement | 10 |
| Engine | 5 |
| Locker | 35 |
| Microwave Oven | 8 |
| Cafeteria | 10 |
| Metals shop | 5 |
| Near flourescent lights | 9 |
| Electricity shop | 12 |
| Outside | 3 |

Counts taken as shown in FIGURE 3-1

| Group | 5 minute shielded count | 5 minute unshielded count |
|---|---|---|
| 1 | 60 | 120 |
| 2 | 130 | 153 |
| 3 | 54 | 92 |
| 4 | 92 | 92 |
| 5 | 64 | 75 |

Q1 - Does background radiation vary from one part of the building to another?

A1 - According to this data, yes, but if one considers statistics probably not.

Q2 - Does background radiation appear to come from radioactive samples stored in the room?

A2 - Room not any different from other places - thus answer no.

Q3 - Did the lead shields affect the count?

A3 - From class data it appears shielded count a little lower.

Q4 - Can you suggest some possible sources of background radiation?

A4 - Cosmic rays, natural radioactive substances.

Part II:

Dosimeters placed in various locations for 7 days:

| Location | mr change in dosimeter |
|---|---|
| Control (in a lead pig) | 15 |
| Gym locker | 11 |
| High altitude (1 flight to San Fran) | 0 |
| Locker | 32 |
| Carried around | 3 |
| Basement | 0 |
| Brick wall | 0 |
| Color TV | 5 |
| Biology room | 12 |
| Medical X-ray - Direct exposure for .3 sec. | 117 |

Q5 - Did any of the dosimeters show a change which could be read?

A5 - Yes.

Q6 - Was any location free of all radiation? (If you can't read any change on the dosimeter, does that mean no radiation was present?)

A6 - Some locations showed no measurable change, however, the change may have been too small to be read. (Recall Part I.)

Q7 - If your dosimeters did show a change, which location showed the highest amount of radiation? The lowest?

A7 - Medical X-ray was the highest; several others showed no measurable change.

Q8 - How many roentgens of exposure occur each second in the chamber?

A8 - 8.8 r/second (our Gammator).

Q9 - Refer to the readings on your dosimeters in this experiment. How long an exposure to your environment would it take to equal the radiation exposure of 1 second in the Gammator?

A9 - Answer depends upon which location the student used.

Control 15 mr/7 days = 2.1 mr/day

Gammator 8800 mr/second

Time needed to be same as 1 second in Gammator: $\frac{1 \text{ day}}{2.1 \text{ mr}} = \frac{x \text{ days}}{8800 \text{ mr}}$

$$x = \frac{8800 \text{ days}}{2.1} = 420 \text{ days}$$

Part III:

Counts taken on filters:

| Corrected c/m before | Corrected c/m after |
|---|---|
| 0 | 28 |
| 0 | 20 |
| 0 | 15 |
| 0 | 29 |
| 0 | 27 |
| 0 | 34 |
| 0 | 35 |
| 0 | 15 |

Q10 - Did any radioactive material (fallout) collect on the filter paper?

A10 - Yes.

Q11 - What can you suggest as possible sources of radiation in our atmosphere?

A11 - Nuclear reactor wastes, sun, natural occurring isotopes in dust, nuclear bomb tests.

Q12 - Considering all parts of this experiment, do you think you can completely escape all radiation?

A12 - No.

Q13 - Is background radiation apparently harmful?

A13 - No.

POSTLAB DISCUSSION:

Tabulate student results on the board so that they can use them to answer the questions.

## EXPERIMENT 3-3: IRRADIATION OF FLOUR BEETLES

The purpose of this experiment is to show that large doses of radiation can kill living organisms.

OBJECTIVES:

Given a Gammator and culture of flour beetles, the student must determine whether radiation can be lethal to living organisms.

ESTIMATED TIME:

Prelab - 5 minutes

Experiment - 15 minutes one day plus 15 minutes the next day

Postlab - 5-10 minutes

MATERIALS:

PER GROUP - 1 hand lens
1 camel hair brush
1 kitchen sieve
1 vial of flour beetles in flour culture medium (about 10 beetles/vial)
Paper towel

PER CLASS - 1 Gammator

ADVANCE PREPARATION:

Prepare flour beetle cultures for each group. (See special materials section.)

HINTS:

None.

PRELAB DISCUSSION:

Ask question - Is radiation harmful to living organisms?

### TYPICAL RESULTS:

| Group | Control |  | Irradiated 24 hours |  |
|---|---|---|---|---|
|  | Living | Dead | Living | Dead |
| 1 | 10 | 0 | 0 | 10 |
| 2 | 10 | 0 | 0 | 10 |
| 3 | 9 | 0 | 0 | 9 |
| 4 | 10 | 0 | 0 | 10 |

Q1 - Was there a significant difference in the percent of living and dead beetles in the two samples?

A1 - Yes, they all died in the irradiated sample

Q2 - Can radiation kill flour beetles?

A2 - Yes.

### POSTLAB DISCUSSION:

Post the results of each group on the board so students can use them to answer questions.

## EXPERIMENT 3-4: EFFECTS OF VARYING RADIATION DOSE ON FLOUR BEETLES

The purpose of this experiment is to (1) show the lethal effects of varying the dose of radiation on animals, (2) show that there will be a period of time before the animals start to die, and (3) determine the dose for an LD-50 for flour beetles.

### OBJECTIVES:

Given a Gammator and flour beetles, the student must determine from graph interpretation of results, the amount of radiation that would be lethal to 50 percent of the population (LD-50/28 days)

### ESTIMATED TIME:

Prelab - 10 to 15 minutes

Experiment - 25 minutes to irradiate beetles

4-10 minute intervals to check beetles at about 7-day intervals

Postlab - 25 or 30 minutes

## MATERIALS:

PER GROUP - Hand lens

Camel hair brush

Kitchen sieve

Flour beetles in flour culture medium

Paper towel

PER CLASS - Gammator

## ADVANCE PREPARATION:

See Special Materials Section for flour beetle instructions and prepare samples of 10 beetles (all one sex) for each group.

## HINTS:

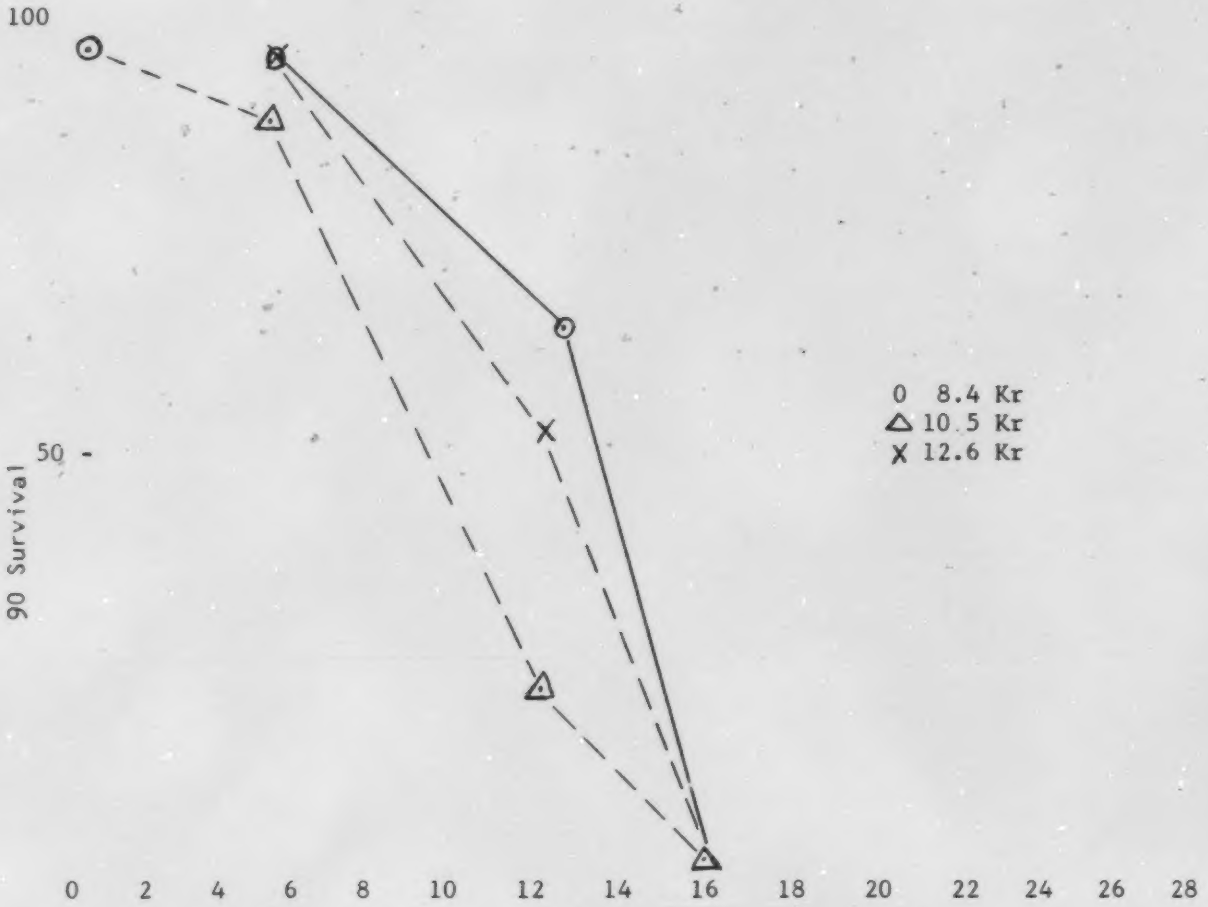
Make sure the flour beetles are sexed so that you have only one sex in a vial. This is to prevent reproduction over the 25 to 30 day period. In order to complete this experiment at the proper time, beetles must be irradiated 28 days in advance.

## PRELAB DISCUSSION:

Give directions so that each group knows what they are to do. Don't comment about results until you are ready for postlab. When they check them make sure they count and record the number living and the number that are dead. The reason behind the experiment will be discussed when the experiment is post labed.

**TYPICAL RESULTS:**

| Irradiation Time (Min.) | Dose (Kr) | 0 Day | | 6 Day | | 12 Day | | 16 Day | | 23 Day | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L | D | L | D | L | D | L | D | L | D |
| 0 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 |
| 4 | 2.1 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | 0 |
| 8 | 4.2 | 10 | 0 | 10 | 0 | 8 | 2 | 8 | 2 | 8 | 2 |
| 12 | 6.3 | 8 | 2 | 5 | 5 | 2 | 8 | 0 | 10 | 0 | 10 |
| 16 | 8.4 | 10 | 0 | 10 | 0 | 6 | 4 | 0 | 10 | 0 | 10 |
| 20 | 10.5 | 10 | 0 | 9 | 1 | 2 | 8 | 0 | 10 | 0 | 10 |
| 24 | 12 6 | 10 | 0 | 10 | 0 | 5 | 5 | 0 | 10 | 0 | 10 |
| 28 | 14 7 | 10 | 0 | 10 | 0 | 2 | 8 | 0 | 10 | 0 | 10 |



Q1 - What dose, in roentgens did your beetles receive while in the Gammator?

A1 - This will depend upon Gammator activity and exposure time.

Q2 - Do some beetles survive each radiation dose?

A2 - Below 8 Kr most live, above 8 Kr most die.

Q3 - Is there any dose of radiation which seems lethal (deadly) to about 50 percent of the population?

A3 - About 10 Kr.

Q4 - Determine the number of days necessary for an LD 50 for each line on your graph.

A4 - Depends upon plot.

POSTLAB DISCUSSION:

Tabulate the results for all the groups on the board. Discuss the questions that we hope to answer. Discuss LD-50. Let the students use the data to complete their write-up.

## EXPERIMENT 3-5: RADIATION EFFECTS ON SEEDS

The purpose of this experiment is to see if irradiation of seeds affects the germination and/or growth of the plant.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - Part I - Count and plant seeds - 30 minutes

Part II - Harvest and measure - 40 minutes (1 week after Part I)

Postlab - 20 minutes

OBJECTIVES:

Given two types of seeds and a Gammator, the student must determine if all seeds have the same (or any) response to radiation, whether irradiation of seeds prevents them from growing into seedlings, and whether irradiation of seeds affects the rate of seedling growth.

MATERIALS:

PER GROUP - Metric rule (10 cm)

Vial for seeds during irradiation

Scissors

PER CLASS - GAMMATOR

2 kinds of seeds (clover and barley)

2 or more seed growing trays about 40 cm x 70 cm

Germinating soil

## ADVANCE PREPARATION:

Have trays with growing soil prepared before the experiment begins Have rows made in the soil and labeled. Dampen the soil and it is easier to make rows

## HINTS:

Have students calculate time of irradiation before they come to class. Plants should be harvested and measured on the same day. Do not cut and leave until the next period.

## PRELAB DISCUSSION:

Explain that each tray will hold one kind of seed and each group will plant one row in each. For example, one tray will contain only clover and one tray will contain only barley One student from each group will plant a row of clover in the appropriate tray, while the other student from the group will plant a row of barley in the other tray.

## TYPICAL RESULTS:

Q1 - How many seeds did you plant?

A1 - 100 of each kind.

Q2 - If 85 of these grew, what would be the percent of survival?

A2 - 85%

| Dose | % Germination | |
|---|---|---|
| kr | Seed A | Seed B |
| 0 | 83 | 89 |
| 2.5 | 81 | 78 |
| 5 | 68 | 74 |
| 10 | 58 | 72 |
| 20 | 58 | 75 |
| 40 | 53 | 83 |
| 80 | 65 | 81 |
| 160 | 52 | 68 |

Q3 - Which of seeds A had the highest percent of germination? Which of Seeds B?

A3 - Non irradiated

Q4 - Which of seeds A had the lowest percent of germination? Which of seeds B?

A4 - 160 kr dose for each A and B.

Q5 - Can irradiation affect seed germination?

A5 - Yes.

Q6 - If so, which seeds, A or B, were most affected?

A6 - A were most affected.

Part II:

| Dose | Ave. Length (mm) | |
|---|---|---|
| kr | Plant A | Plant B |
| 0 | | 15 |
| 2.5 | 84 | 12 |
| 5 | | |
| 10 | 75 | 15 |
| 20 | | |
| 40 | 79 | 12 |
| 80 | 36 | 12 |
| 160 | 10 | 12 |

Q7 - Which of plants A had the longest average? Which of B?

A7 - 0 & 2.5 kr, 0 kr.

Q8 - Which of plants A had the shortest average? Which of B?

A8 - 160 kr for A, 40 to 160 kr B, not really significant.

Q9 - Can irradiation of seeds affect growth of plants?

A9 - Yes.

Q10 - If so, was A or B most affected?

A10 - A.

POSTLAB DISCUSSION:

Tabulate all of the results on the blackboard and let the students use these results to complete their write-up.

## EXPERIMENT 3-6: RADIATION AND LIFE

The purpose of this experiment is to use the data from the last five experiments to arrive at some generalizations concerning the effect of radiation on life.

### OBJECTIVES:

Given the results of labs 3-1 through 3-5, the student must differentiate between somatic and genetic radiation effects and recognize that radiation effects on an individual of a population will vary from other individuals in the same population.

### ESTIMATED TIME:

Prelab - none

Experiment - 40-45 minutes

Postlab - 5-10 minutes if necessary

### MATERIALS:

PER GROUP - Results of Experiments 3-1 through 3-5

Lab notebook and pencil

### ADVANCE PREPARATION:

None

### HINTS:

None

### PRELAB DISCUSSION:

None.

### TYPICAL RESULTS:

Q1 - Is it possible to tell, in advance, how much radiation it would take to kill a given mouse?

A1 - No.

Q2 - How could you express the expected lethal effects of another 400 roentgen radiation dose on a similar group of mice?

A2 - LD-25 3 weeks or about 5 mice will die within 3 weeks.

Q3 - Why do you think that a radiation dose which kills some mice, doesn't kill them all?

A3 - Depends upon their physical condition.

Q4 - What evidence have you that the change in fur color resulted from the radiation exposure?

A4 - All irradiated mice have a color change while the control group retained the same color.

Q5 - Was the change in fur color of the 15 mice a genetic or a somatic effect?

A5 - Somatic.

Q6 - What experiments have you done in which somatic damage occurred?

A6 - Seed germination, flour beetle deaths.

Q7 - Have you done any experiments in which genetic changes occurred? If so, which experiment(s)?

A7 - No.

Q8 - Suppose that some of the 15 surviving mice reproduced. Would you expect their offspring to have grey fur? Explain

A8 - No, the change in fur color was an immediate effect and was not caused by damage to the reproductive organs.

Q9 - All of the original mice had brown eyes. The offspring of a pair of the irradiated mice had pink eyes Was this change of eye color a genetic or somatic effect?

A9 - Genetic.

Q10 - Suppose two of the pink-eyed mice were mated. Would you expect some or all of their offspring to have pink eyes?

A10 - Yes.

Q11 - Another group of mice were given a dose of 50 roentgens a week for 10 weeks. All of these mice continued to survive. How could you explain their survival even though they received a larger total dose than the original group?

A11 - Their dose was spread over a longer period of time - this gives cells time to repair damage plus not as many cells are damaged at one time.

Q12 - Although the probability of occurence is extremely low, a single radiation particle or ray, in the right spot, can produce a mutation. Would spreading a dose of radiation over a long period of time reduce the chance of genetic damage?

A12 - Not necessarily.

Q13 - Would spreading a dose of radiation over a long period of time reduce the change of permanent somatic damage?

A13 - Yes.

Q14 - Would you expect the lethal dose for man to be the same as the lethal dose for mice? (Remember the results of the seed irradiation experiment.)

A14 - No.

Q15 - If a person is exposed to a relatively large dose of radiation and feels no ill effects, can he be sure that no genetic damage has occurred? Explain.

A15 - No, genetic damage wouldn't show up until a later generation

Q16 - In terms of genetic damage which part of the body should be most protected from radiation exposure?

A16 - Reproductive organs

### POSTLAB DISCUSSION:

Answer any questions students have on the experiments.

## EXPERIMENT 3-7: SAFE HANDLING OF RADIOACTIVE LIQUIDS

The purpose of this experiment is to develop safe techniques for handling radioactive liquids.

### OBJECTIVES:

Given directions for the safe handling of radioisotopes and a radioisotope, the student must practice the safe handling of radioactive liquids.

### ESTIMATED TIME:

Prelab - 25 minutes

Experiment - 45 minutes

Postlab - none

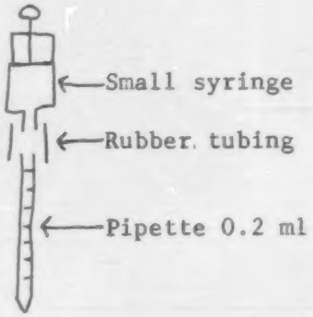
MATERIALS:

PER GROUP - 1 safety tray
- 1 safety tray liner
- 2 pair disposable plastic gloves
- 1 ml of liquid radioisotope (see hint)
- 1 small test tube (about 75 to 100 mm)
- 1 test tube rack
- 1 syringe pipette, small as one can get
- 1 beaker
- 1 planchet
- 1 eye dropper pipette
- 1 forceps
- heat lamp
- 1 G-M tube & scaler

PER CLASS - 1 can talcum powder
- 2 or 3 survey meters
- 1 roll radiation warning labels
- 1 box wiping tissues
- Detergent
- 1 radioactive wastecan
- Distilled water

ADVANCE PREPARATION:

See diagram on how to set up a syringe pipette



HINTS:

For a radioactive liquid it is convenient to use a minigenerator Sn/In (see equipment list). One can milk this generator into a container to be used as the radioactive liquid. It has a short half-life (100 minutes) so in case of spill, decontamination will not be a serious problem. If you use this isotope, you will have to make your counts the same day. It cannot be held until the next lab period. If it is necessary to continue the lab on a second day, the Sr/Y minigenerator (half-life: 64 hr) may be used.

PRELAB DISCUSSION:

Go over the experiment thoroughly emphasizing safety techniques. Have students read Appendix A which deals with laboratory safety.

TYPICAL RESULTS:

None.

POSTLAB DISCUSSION:

None.

## EXPERIMENT 3-8: CONTAMINATION AND DISPOSAL

The purpose of this experiment is (1) examine contamination problems as they relate to various types of surfaces, (2) examine contamination problems as they relate to the type of source, and (3) "clean up" and disposal of radioactive wastes.

OBJECTIVES:

Given a liquid isotope, scaler, and several sample materials of various surface textures, the student must determine which surface is most difficult to decontaminate, which surface is the least difficult, compare the seriousness of contamination with different isotopes, write about present day methods and future methods of disposing of radioactive waste, list advantages and shortcomings of each method, and describe step by step procedures you would follow in the event you spilled a tube containing a liquid radioisotope.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 45 minutes

Postlab - 30 minutes

MATERIALS:

PER GROUP - Scaler and G-M tube
Heat lamp
Small vial
Safety tray and liner
Plastic gloves

Eye dropper pipette
2 wooden splints or blocks

PER CLASS - Small samples of glass, wood, metal (shiny & rusty), painted wood, rubber, brick or concrete, and cloth

| | |
|---|---|
| Minigenerators | Strontium 90/Yttrium 90<br>Cesium 137/Barium $137^m$ |

Soap or detergent
Radiation warning labels
Resource materials for radioactive disposal

ADVANCE PREPARATION:

Obtain resource materials for Part III. The A.E.C. booklet "Radioactive Wastes" is a good source. Most general books on atomic energy also contain sections on waste disposal.

HINTS:

Have the students use only one or two samples in Part I and "pool" their data at the end. Part II measure distance of block to sample so they can get nearly the same geometry 24 hours later.

PRELAB DISCUSSION:

Tell the students that they are to select one or two samples for use in Part I. Point out the resource materials available for Part III.

Part I Data:

| GROUP | MATERIAL | CORRECTED c/m | AFTER RINSING c/m | AFTER SCRUBBING c/m |
|---|---|---|---|---|
| 1 | Glass | 676 | 24 | 0 |
| 2 | Wood | 1217 | 958 | 678 |
| 3 | Rusty Metal | 897 | 411 | 188 |
| 4 | Shiny Metal | 736 | 35 | 0 |
| 5 | Rock | 501 | 478 | 503 |
| 6 | Rubber | 2033 | 664 | 221 |
| 7 | Painted Wood | 3460 | 777 | 0 |
| 8 | Concrete | 826 | 662 | 634 |

Part II DATA:

| GROUP | YTTRIUM 90 | YTTRIUM 90 (24 hr) | BARIUM 137 | BARIUM 137 (24 hr) |
|---|---|---|---|---|
| 1 | 9 | 0 | 43 | 0 |
| 2 | 194 | 114 | 22 | 0 |
| 3 | 118 | 116 | 38 | 0 |
| 4 | 35 | 31 | 47 | 13 |
| 5 | 44 | 17 | 73 | 5 |
| 6 | 13 | 9 | 14 | 0 |

Part I:

Q1 - Which samples have remained most contaminated?

A1 - Wood.

Q2 - Which (if any) samples remain most contaminated after scrubbing with soap and water?

A2 - Rock and concrete.

Q3 - What type of material would you recommend for the counter tops and walls in areas where radioactive liquids are to be used?

A3 - Polished non-porous finish.

Part II:

Q4 - Which would present a more serious problem, spillage of Yttrium-90 or Barium-$137^m$? Why?

A4 - Yttrium-90 since it remains radioactive for a longer period of time.

Part III:

Q5 - What are the most common methods now being used to dispose of radioactive wastes?

A5 - Burial, dilution, conversion liquid to solid.

Q6 - Are any of these methods entirely satisfactory? Explain.

A6 - No, there is still radiation left even though it is buried. (Answer will depend somewhat on A5.)

Q7 - What are some other possible methods of disposal that might be used in the future?

A7 - Recycling, launch into space

Q8 - Suppose you were to drop a test tube containing a fairly large amount of a liquid radioisotope. It hits the work counter and breaks. The liquid spatters on the work counter, the floor, your shoes, your arm, your sleeve and your books. Describe the step by step procedure you would follow after the accident. Assume your instructor is unavailable to assist you.

A8 - Wash thoroughly with soap and water.

Rinse several times.

Monitor all areas.

Repeat washing and rinsing until monitoring shows no significant count.

If clothing and area is still contaminated leave in the area and mark it with radiation warning signs.

POSTLAB DISCUSSION:

Tabulate student results for Part I and Part II on the blackboard so they can use them to answer the questions. Discuss current disposal techniques being used.

## EXPERIMENT 3-9: INTAKE OF RADIOACTIVE PHOSPHOROUS BY FISH

The purpose is to show that radioactive materials taken into the body may be incorporated into the body structure.

OBJECTIVES:

Given a living goldfish, Phosphorous-32, film pack, and developer, the student must determine if the radioisotope has an affinity to any one organ of the body of the fish; and, if so, to identify which organ, and write reasons why radioactive materials taken into the body have more danger potential than periodic exposure to external radiation.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 90 minutes

Postlab - 10 minutes

MATERIALS:

PER GROUP - 2 live goldfish
1 Dissection kit
Autoradiograph materials
Safety tray and liner
Disposal plastic gloves

PER CLASS - 2 smooth walled aquariums (2 wide mouth gallon jars will do) with aerator
Phosphorous-32 (10 microcuries)
Dip net
4 beakers
Anesthetizing solution
Plastic wrap
Hot plate or bunsen burner
Radiation warning labels

ADVANCE PREPARATION:

Order the Phosphorous-32 so it arrives within a week of when you are to use it. Make sure that you will be able to acquire the fish for this experiment.

HINTS:

Make sure the fish parts are left on the film only overnight and not over a weekend. Otherwise all parts will appear to have an equal amount of Phosphorous-32 absorption. When observing film exposure, have students look for darkness of exposure, not size of spot. (A large muscle will show a big spot but might not be as dark as from a small bone.)

PRELAB DISCUSSION:

Very little discussion needed when they put the fish in the tanks. Before they sacrifice the fish and do the dissection, you will have to review these techniques.

TYPICAL RESULTS:

| Fish Parts | Fish in tank with Radioactive phosphorous | Control |
|---|---|---|
| Skeleton | Exposed (dark) | Not exposed |
| Internal organs | Exposed | Not exposed |
| Muscle | Exposed | Not exposed |

Q1 - Is either of the fish radioactive? Explain.

A1 - Yes, the one in the radioactive phosphorous exposed the film.

Q2 - If either of the fish were radioactive, which part(s) were the most radioactive?

A2 - The skeleton.

Q3 - Explain why one part might contain more radioactivity than another?

A3 - Phosphorous deposited more in this area

Q4 - Why should radioactive materials taken into the body be more dangerous than periodic exposure to external radiation?

A4 - The substances may be deposited in specific areas and thus kept in the body.

Q5 - Assume that some milk cows feed upon grass which is contaminated with radioactive strontium fallout. Explain how this radioactive strontium could end up in your bones.

A5 - Drink the milk which contains radioactive strontium. The strontium being similar to calcium would be used by the body to make bones.

POSTLAB DISCUSSION:

Compare results. Discuss questions - especially number 5.

## EXPERIMENT 3-10: INTERNAL AND EXTERNAL RADIATION

The purpose of this lab is to (1) show that some types of radiation are more dangerous than others, and (2) compare the dangers of external and internal radiation.

OBJECTIVES:

Given the results of Experiment 2-9 and questions to guide thinking, the student must compare the relative dangers of radiation inside the body as opposed to outside the body, apply these comparisons to alpha, beta, and gamma radiation, write the manner in which radiation is harmful to living cells, and write a comparison of the effect of radioisotopes which demonstrate an affinity to specific tissue as opposed to radioisotopes which distribute generally throughout the body of an organism

ESTIMATED TIME:

Prelab - none

Experiment - 60 minutes

Postlab - 10-15 minutes

MATERIALS:

PER GROUP - Laboratory notebook
Pencil

ADVANCE PREPARATION:

None.

HINTS:

None

PRELAB DISCUSSION:

None

TYPICAL RESULTS:

Q1 - Which type of radiation is most penetrating?

A1 - Gamma.

Q2 - Which type of radiation is least penetrating?

A2 - Alpha

Q3 - Which particle has the greater charge, alpha or beta?

A3 - Alpha

Q4 - Which particle is heavier, alpha or beta?

A4 - Alpha

Q5 - If they have the same amount of energy, which is moving faster, alpha or beta?

A5 - Beta

Q6 - Which would exert a greater force on the electrons of the atom?

A6 - Alpha.

Q7 - Based on your answer to number 6, which particle would produce the most ion pairs in .1 cm of travel?

A7 - Alpha

Q8 - Now think about the ability of the 2 particles to penetrate. If both particles have the same amount of energy and if the formation of each ion pair requires a specific amount of energy, which particle could travel further before it runs out of energy?

A8 - Beta.

Q9 - Based upon these answers, which particle should have the greatest range?

A9 - Beta.

Q10 - Does this agree with your observations from Experiment 2-1?

A10 - Yes

Q11 - Compared with alpha and beta radiation, would you expect it to travel farther or not as far to expend its energy?

A11 - Further

Q12 - Which arrow represents the path of the alpha particle, which the beta particle and which the gamma ray?

A12 - #1 - gamma
#2 - beta
#3 - alpha

Q13 - Which type of external radiation can cause skin burns but cannot damage internal organs?

A13 - Beta.

Q14 - Which type of external radiation will not damage any living tissue in your body?

A14 - Alpha

Q15 - Which type of external radiation could affect your internal organs?

A15 - Gamma.

Q16 - Sometimes internal tumors are treated by irradiating them with beams of external radiation. Which type of radiation must be used?

A16 - Gamma.

Q17 - Is exposure of the skin to external alpha radiation dangerous?

A17 - No.

Q18 - Which type of external radiation presents the greatest hazard?

A18 - Gamma.

Q19 - Which radiation produces its ionization within the shortest distance?

A19 - Alpha.

Q20 - Remember that the more ionizations that occur within a cell, the more likely the cell is to die If sources of alpha, beta, and gamma radiation are in a cell, which is most likely to kill it?

A20 - Alpha

Q21 - Is internal alpha radiation dangerous?

A21 - Yes.

Q22 - Which radiation might escape the body without expending all of its energy?

A22 - Gamma.

Q23 - How would the number of ion pairs formed by the alpha and the beta compare?

A23 - The same.

Q24 - Which radiation would produce the greatest concentration of ion pairs?

A24 - Alpha.

Q25 - Which animal would show the largest radiation concentration in each of the above tissue samples.

A25 - Muscle A
Bone B
Thyroid C

Q26 - In each of the above cases, comment on the possible effect to the surrounding tissues

A26 - The surrounding tissues would be most damaged in animal C but the damage would not extend very far. A large amount of tissue would be affected in animal A but the concentration of damage would be small.

Q27 - From the information you have learned about tissue seeking isotopes, can you suggest examples of how they might be used in medical science?

A27 - Used to determine whether a particular part is functioning properly.

Treat a growth in a particular area

POSTLAB DISCUSSION:

Go over questions with students.

TEXT MATERIAL - PAGES 78-80

Have students read these pages Class discussion probably isn't necessary unless students have questions

## INTRODUCTION TO CHAPTER 4

Having learned of the dangers of radiation in Chapter 3, the student explores the various means of radiation protection in Chapter 4

The chapter begins with an exercise in using semi-logarithmic graph paper which will be used throughout the chapter.

The student investigates the effects of time, distance, shielding, and scattering, on radiation exposure. Units for measuring quantity of radiation and quantity of radiation exposure are also discussed. Finally, the student considers how much radiation exposure is too much.

As with previous chapters, the teacher should remain as much in the background as possible to allow for maximum student discovery.

## CHAPTER 4

Assign Appendix E before beginning Experiment 4-1.

### EXPERIMENT 4-1: RADIOACTIVITY AND TIME #1

The purpose of this experiment is to (1) show that the amount of radiation changes with time and (2) introduce the idea of half-life.

OBJECTIVES:

Given a minigenerator, scaler and graph paper (regular and semi-log) the student must compare count rates of a given source at given intervals of time, observe the decrease of count rates over a time span, and determine the half-life of that particular source.

ESTIMATED TIME:

Prelab - 15 minutes

Experiment - 25-30 minutes

Postlab - 15 minutes

MATERIALS:

PER GROUP - Planchet
G-M tube and scaler
Ringstand
Buret clamp

Safety tray and liner

Plastic gloves

Regular graph paper

Semi-log graph paper (2 cycle)

PER CLASS - Minigenerator (Cesium 137/Barium $137^m$)

Timer (clock with sweep second hand will do)

ADVANCE PREPARATION:

None

HINTS:

A count rate meter could be used if you have one.

PRELAB DISCUSSION:

You will need to discuss the technique used. They confuse the class timer, which they will use to get the total elapsed time, with the time they get from the timer on their scalers, which is being used to determine the counts/minute for the various intervals of the total time

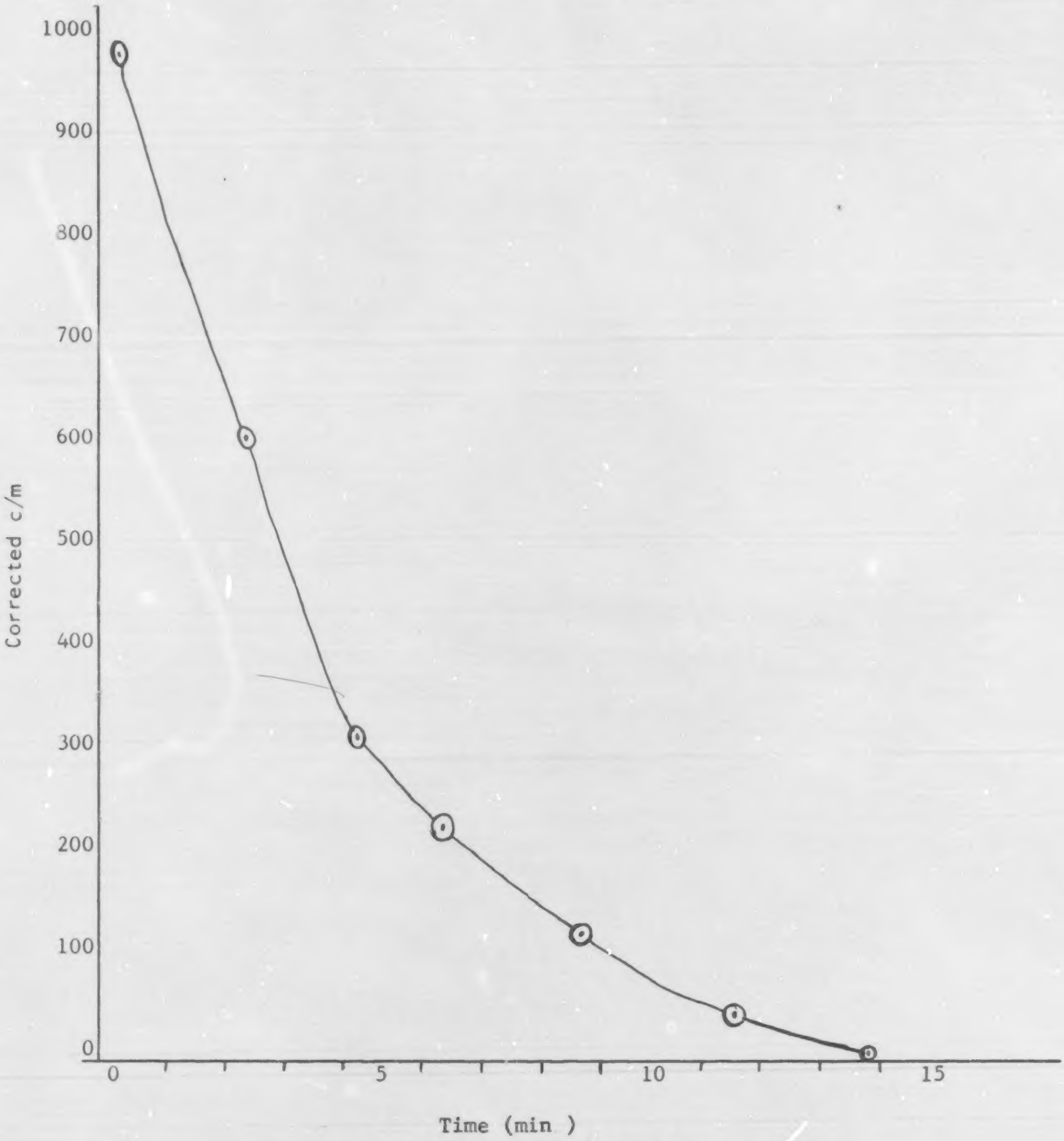
TYPICAL RESULTS:

Q1 - Do your recorded values show a significant change during the 15 minutes?

A1 - Yes

Q2 - If there is a change, does it appear to be the result of a random fluctuation or does it appear to vary according to a pattern?

A2 - The change follows a pattern.



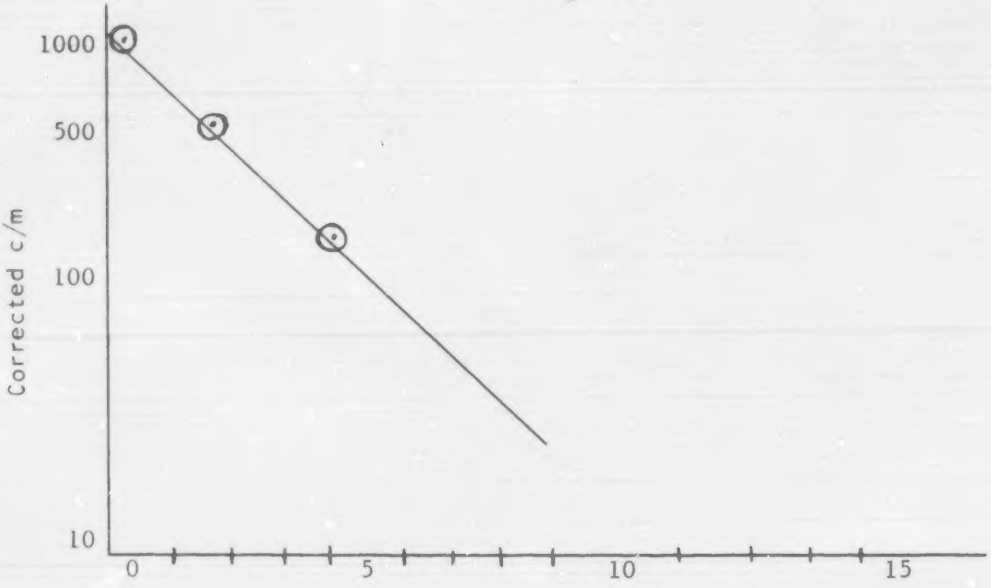
Q3 - Did the count rate change at a constant rate?

A3 - No.

Q4 - Does there appear to be any predictable pattern in the variation?

A4 - Yes, there is a pattern.

Semi-log Plot



Time (min.)

Q5 - What is the general shape of this graph?

A5 - Straight line.

Q6 - Using either or both graphs, determine the time required for the counts/minute to drop to half its original value.

A6 - From the first curve about 3.1 minutes; from the semi-log plot about 2.6 minutes

Q7 - What additional time is required for the counts/minute to again be cut in half? (¼ the original value)

A7 - About 2.6 minutes

Q8 - Which graph is easiest to use in determining these values?

A8 - Straight line graph (semi-log graph)

Q9 -Without referring to your graphs, predict the time for the counts/minute to be cut in half once again.

A9 - 2.6 minutes.

Q10 - Now use your graphs to check your prediction. How accurate was your prediction?

A10 - Accurate.

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Q11 - How would you describe the way in which radioactivity changes with time?

A11 - Radioactivity decreases with time.

Q12 - What is the half-life of the radioisotope which you used in this experiment?

A12 - 2 6 minutes.

Q13 - What was the advantage of plotting the data on semi-log graph paper?

A13 - Get a straight line

### POSTLAB DISCUSSION:

Time spent here will depend upon how well the students are able to plot the material. The idea of smooth curves must be emphasized

## EXPERIMENT 4-2: RADIOACTIVITY AND TIME #2

The purpose of this experiment is to show that different radioactive materials decay at different rates (have different half-lives)

### OBJECTIVES:

Given a minigenerator source, scaler and graph paper, the student should graph the time required for the radioactivity of this sample to decrease to half its former value, and compare this time with the half-life for the sample used in the previous experiment. The student must identify that different sources of radioactivity have different half-lives.

### ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 30 minutes first day

5 minutes on each of next 4 days

Postlab - 15 minutes

### MATERIALS:

PER GROUP - G-M tube and scaler
- Timer
- Planchet with concentric depressions
- Ringstand and buret clamp
- Safety tray and liner
- Plastic gloves

Semi-log graph paper

Heat lamp

PER CLASS - Sr/Y Minigenerator

Wall timer

Radiation warning label tape

## ADVANCE PREPARATION:

None

## HINTS:

The first part of the experiment they use the same technique as for Experiment 4-1 until they find that the decay rate is not fast enough to get results in this short period of time You can have the planchets all placed on one tray and let them evaporate overnight Or one heat lamp may be used to hasten the evaporation It is extremely important that the same geometry is maintained throughout this experiment. One method for insuring this is to use the technique shown in Figure 4-8, page 98 of the text. If this technique is used, the sample *must* first be dry

## PRELAB DISCUSSION:

Very brief since the technique is the same as for Experiment 4-1. After the students discover that the decay rate is too slow for them to get results in a class period, you may want to discuss the drying technique and geometry that you decide to use

## TYPICAL RESULTS:

Q1 - Did the count rates change in a fashion similar to Experiment 4-1?

A1 - No, no change

Q2 - Was there a significant change in the count rate during the 15 minutes?

A2 - No

Q3 - Is there now a significant change in the activity of your sample?

A3 - There was a little change.

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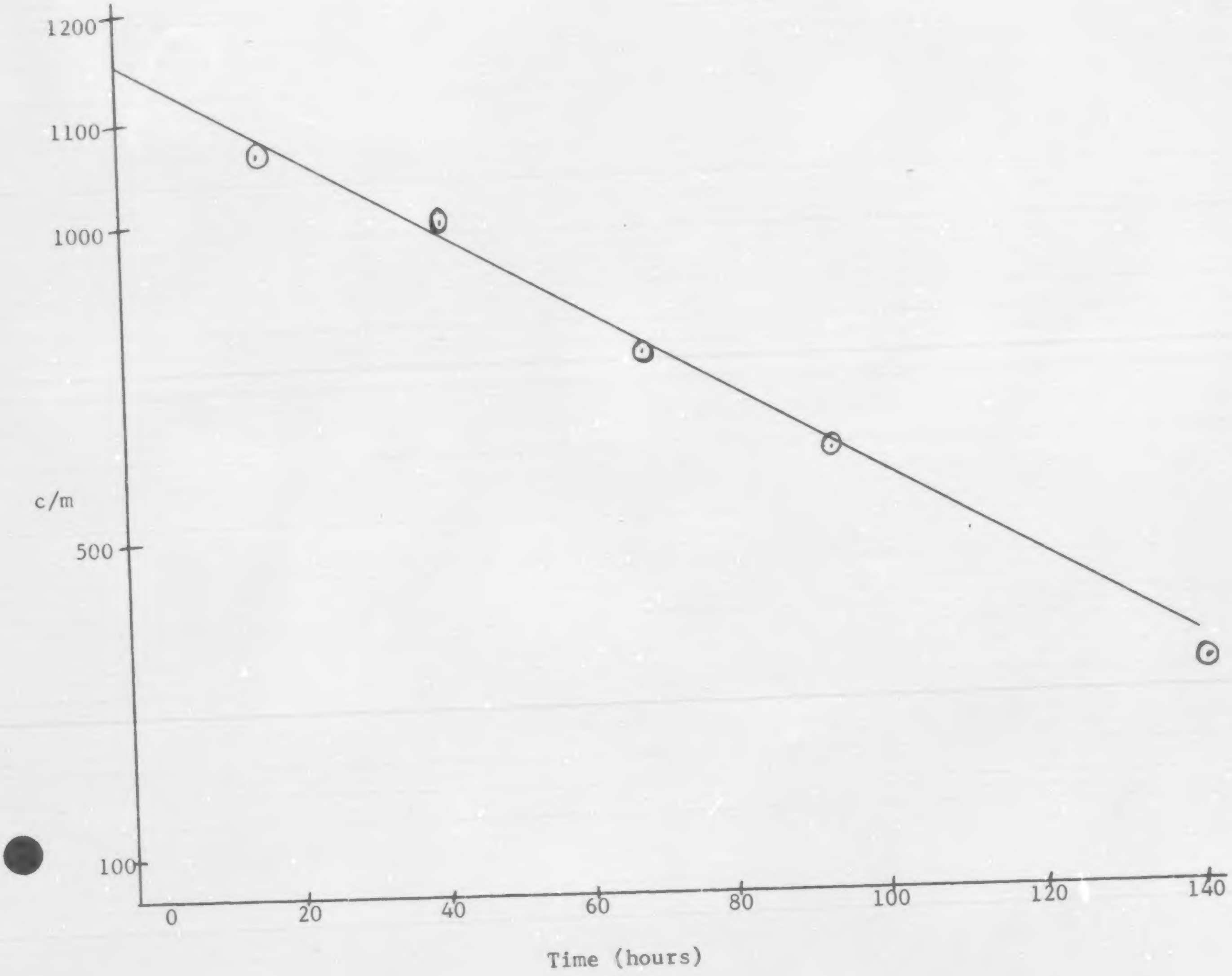
| Time (hr) | c/m | Corrected c/m |
|---|---|---|
| 0 | 1208 | 1106 |
| 48 | 1029 | 983 |
| 72 | 699 | 663 |
| 96 | 518 | 493 |
| 144 | 268 | 241 |



Q4 - Is the shape of your graph similar to the Experiment 4-1 graph?

A4 - Yes, a straight line.

Q5 - If there is any difference, how do they differ?

A5 - The time axis is in hours rather than minutes or it has a different slope

Q6 - Can you determine the half-life of this sample? If so, what is it?

A6 - Yes, about 65 hours.

Q7 - Refer to Appendix D in the back of this book. Which radioisotopes do you think were used in Experiment 4-1 and Experiment 4-2?

A7 - Experiment 4-1 - Barium 137
Experiment 4-2 - Yttrium 90

Q8 - How many counts/minute would you predict for your source 10 days after you made the initial count in this experiment?

A8 - In 10 days one would have 240 hours. This is $\frac{240}{64} = 3.75$ half-lives.

Thus, if the initial count was 1,000 the first half-life would make it 500, second 250, third 125, fourth 63. Thus, it would be about 75 c/m or so.

Q9 - If you measured the activity of a different sample every day for 5 days and found no significant change, what do you think might be the reason?

A9 - Very long half-life.

Q10 - Sample A has a half-life of 1 hour. Sample B has a half-life of 10 hours. An initial count is taken on each sample. One hour later each sample showed a count of 400 c/m. Which sample had the highest initial count?

A10 - Sample A

Q11 - How long after the activity was 400 c/m would sample A show an activity of 100 c/m?

A11 - Since half-life is 1 hour, at end of first hour, it would be 200 c/m, at the end of second hour 100 c/m - thus 2 hours.

Q12 - How long after the activity was 400 c/m would sample B show an activity of 100 c/m?

A12 - Half-life is 10 hours. At end of 10 hours count would be 200 c/m. At the end of second 10 hours it would be 100 c/m - 20 hours.

Q13 - Which sample presents the greatest disposal problem? Explain.

A13 - Sample B since it has a longer half-life. It would remain radioactive for a longer period of time.

POSTLAB DISCUSSION:

Go over questions, compare answers and make sure they all understand the questions.

EXPERIMENT 4-3: RADIATION AND DISTANCE

The purpose of this experiment is to investigate the effect of distance on radiation exposure.

OBJECTIVES:

Given a radioactive source, scaler, and calibrated board, the student should identify the effect that distance has on the amount of radiation received from a source

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 30-35 minutes plus 25 to 30 minutes calculator time

Postlab - 20 minutes

MATERIALS:

PER GROUP Radioactive disc (gamma)
G-M tube and scaler
Timer
Calibrated board

PER CLASS - Electronic calculator (if available)

ADVANCE PREPARATION:

None

HINTS:

The students have trouble graphing and calculating $1/D^2$ You may want to give some class time to help with the graphing and calculating. It is very helpful to use an electronic calculator in these calculations.

### PRELAB DISCUSSION:

Make sure they do the experiment and answer the questions in sequence. Q1 and Q2 are meant to be answered from their first graph.

### TYPICAL RESULTS:

BACKGROUND: 32 c/m

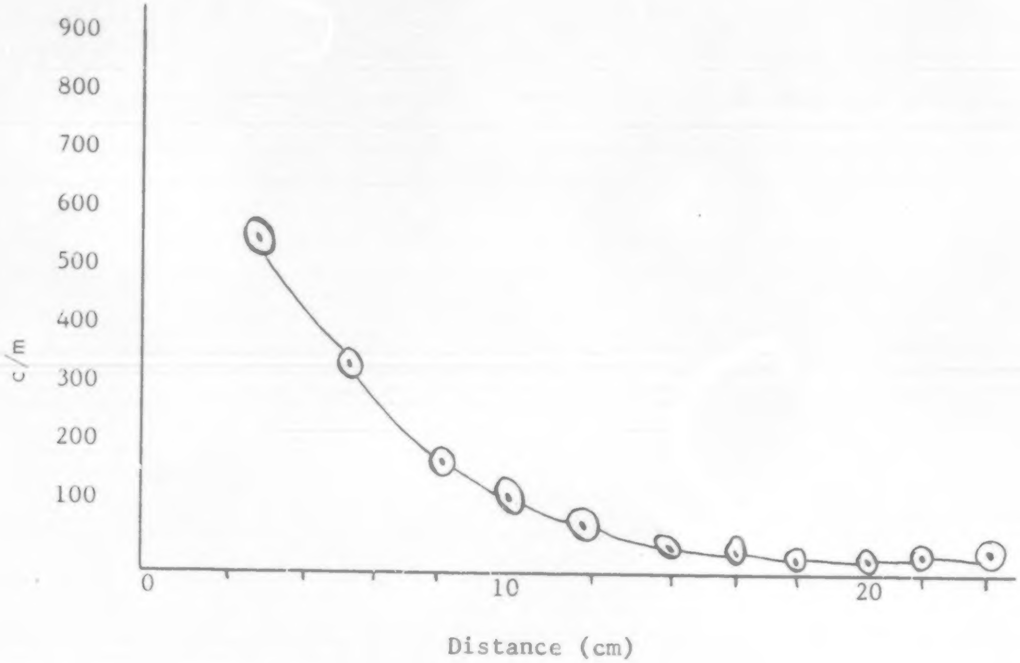
| D (cm) | c/m | Corrected c/m | $D^2$ | $1/D^2$ |
|---|---|---|---|---|
| 4 | 585 | 553 | 36 | 0.0625 |
| 6 | 337 | 305 | 36 | 0.0278 |
| 8 | 213 | 181 | 64 | 0.0156 |
| 10 | 153 | 121 | 100 | 0.0100 |
| 12 | 122 | 90 | 144 | 0.00694 |
| 14 | 98 | 66 | 196 | 0.00510 |
| 16 | 77 | 44 | 256 | 0.00391 |
| 18 | 79 | 47 | 324 | 0.00309 |
| 20 | 62 | 30 | 400 | 0.00250 |
| 22 | 59 | 27 | 484 | 0.00207 |
| 24 | 54 | 22 | 576 | 0.00174 |

Q1 - Does distance from the source affect the counts/minute?

A1 - Yes, the farther the source, the less count received.

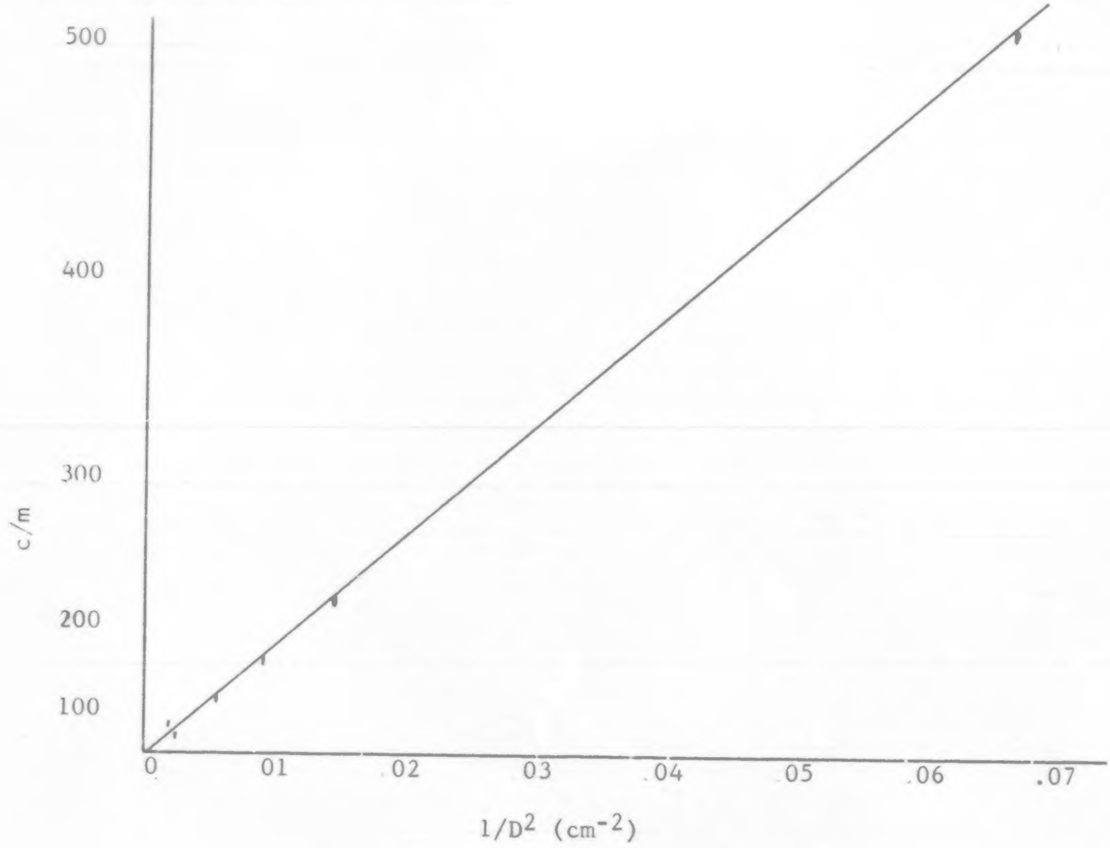
Q2 - Does it change a little bit or a lot?

A2 - It changes a great deal at first, then the changes are smaller.



Q3 - When D doubles, what happens to the value of $1/D^2$?

A3 - It becomes ½ or it decreases



Q4 - What is the general shape of the graph?

A4 - Straight line.

Q5 - What does a graph of this shape mean? If you don't know, discuss it with your instructor.

A5 - It means the amount of radiation received varies directly with the inverse square of the distance.

Q6 - If you double your distance from a radioactive source, what effect does it have on the radiation exposure which you receive?

A6 - It cuts it to ½.

Q7 - If the activity 10 cm from a source is 450 counts/minute, what would you predict for the activity 30 cm from the same source?

A7 - Since the distance is tripled the count will decrease to 1/9 of 450 = 50 c/m.

Q8 - Would the radiation become zero at very large distances? Explain.

A8 - No, it will approach zero, but will never become zero.

Q9 - Which would reduce the radiation dose by a greater amount?

A. Cutting the time of exposure in half.

B. Doubling the distance from the source.

A9 - B

Q10 - A G-M tube, connected to a scaler, is placed 6 cm from a radioactive sample. In one minute, 400 counts are detected. If you placed the G-M tube 12 cm from the same source, how long should it take before 400 counts were detected?

A10 - If you double the distance the count will become ¼ x 400 = 100 c/m. Thus it would take 4 minutes to receive the same count.

POSTLAB DISCUSSION:

They may need help understanding what is meant by "doubling the distance" or "tripling the distance", etc. You may have to help with these questions. It will depend upon the amount of math they have had or understand.

## EXPERIMENT 4-4: BETA SHIELDING

The purpose of this experiment is to determine the shielding effects of various materials on beta radiation.

### OBJECTIVES:

Given a radioactive beta source, scaler, cardboard, aluminum and lead, the student should identify the relative effectiveness of these materials as shields for beta radiation and determine the half thickness of aluminum for this beta radiation.

### ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 35 minutes

Postlab - 10 minutes

### MATERIALS:

PER GROUP - Radioactive disc (beta)
G-M tube and scaler
Timer
20 sheets of cardboard
6 sheets of aluminum
2 or 3 sheets of lead
Regular and semi-log graph paper
Calibrated board
Vernier caliper or micrometer

PER CLASS - Electronic calculator (if available)

### ADVANCE PREPARATION:

None.

### HINTS:

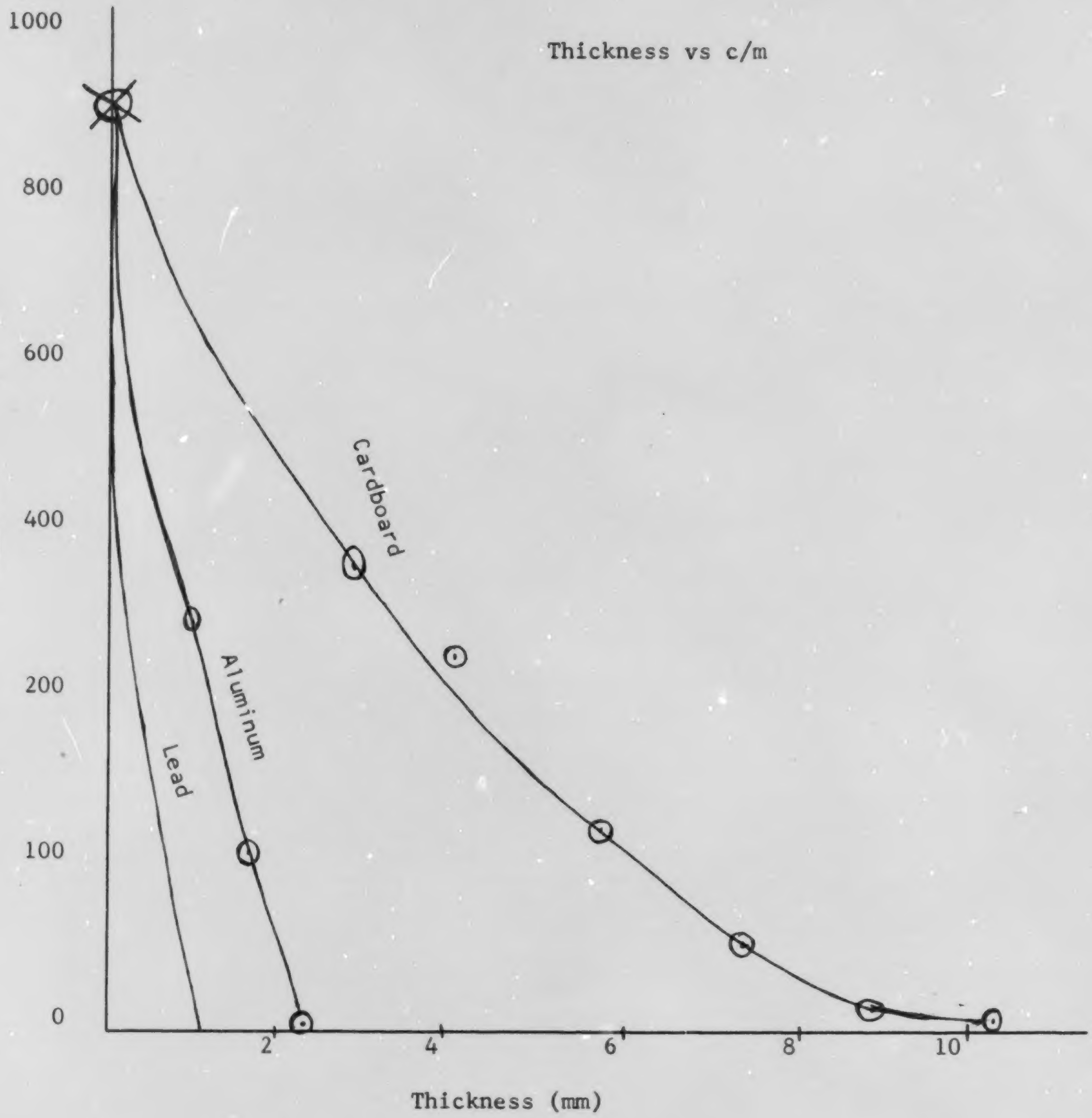
If you do not have a micrometer or vernier caliper, you could stack the sheets and measure the thickness with a meter stick. In this way, you could divide the number of sheets into the thickness to get the thickness of one sheet. You should have uniform sheets of aluminum, cardboard, and lead. An electronic calculator would be helpful for calculating total thickness.

## PRELAB DISCUSSION:

You may want to go over how to use and read the micrometer or vernier caliper before they start the experiment. Or you may find it easier to help them as they are doing the experiment. Emphasize third sentence in procedure, they should get a strong initial count.

## TYPICAL RESULTS:

| | | CARDBOARD | | | ALUMINUM | | | LEAD | |
|---|---|---|---|---|---|---|---|---|---|
| No. of Shields | c/m | Corrected c/m | Thickness (mm) | c/m | Corrected c/m | Thickness (mm) | c/m | Corrected c/m | Thickness (mm) |
| 0 | 922 | 886 | 0 | 922 | 996 | 0 | 922 | 886 | 0 |
| 1 | | | | 309 | 273 | .8 | 83 | 47 | 1.0 |
| 2 | 592 | 518 | 1.5 | 122 | 86 | 1.7 | | | |
| 3 | | | | 36 | 0 | 2.5 | | | |
| 4 | 402 | 366 | 3.0 | | | | | | |
| 6 | 254 | 218 | 4.4 | | | | | | |
| 8 | 141 | 105 | 5.9 | | | | | | |
| 10 | 87 | 51 | 7.4 | | | | | | |
| 12 | 63 | 27 | 8.9 | | | | | | |
| 14 | 57 | 21 | 10.4 | | | | | | |



Q1 - By comparing graphs, determine how the shielding abilities of aluminum and cardboard compare.

A1 - Aluminum is a much better shield than cardboard. About 5 times better.

Q2 - How many sheets of cardboard would be necessary to absorb as much radiation as one sheet of aluminum?

A2 - About 5 sheets.

Q3 - What (if any) advantage does the semi-log paper have?

A3 - Gives a straight line and is easier to read

Q4 - What thickness of cardboard will stop half the beta radiation?

A4 - About 2.4 mm (our source).

Q5 - What is the half-thickness of aluminum for your beta radiation?

A5 - About 0.4 mm (our source).

POSTLAB DISCUSSION:

Go over the questions. You may have to discuss half-thickness in a little more detail.

## EXPERIMENT 4-5: GAMMA SHIELDING

The purpose of this experiment is to compare the shielding effects of various materials on gamma radiation and compare the shielding of gamma and beta radiation.

OBJECTIVES:

Given a radioactive gamma source, scaler, aluminum and lead, the student should identify the relative effectiveness of these materials as shields for gamma radiation.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 45 minutes

Postlab - 15 minutes

MATERIALS:

PER GROUP - Radioactive disc (gamma)
G-M tube & scaler
Timer
80 Aluminum sheets
20 Lead sheets
Regular and semi-log graph paper
Calibrated board
Vernier caliper or micrometer

PER CLASS - Electronic calculator (if available)

## ADVANCE PREPARATION:

None

## HINTS:

Students may need to share aluminum and lead shields to get the large number required. Taping shields in groups of 10 may facilitate procedures.

## PRELAB DISCUSSION:

Very brief since the procedure is similar to the last experiment.

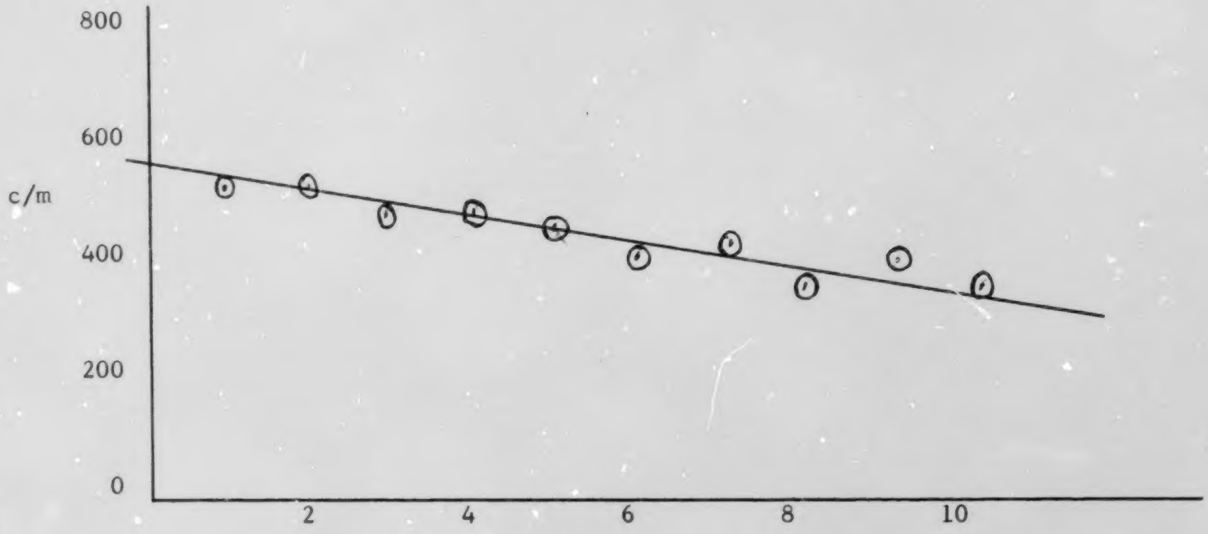
## TYPICAL RESULTS:

| LEAD<br>c/m | NUMBER OF SHEETS |
|---|---|
| 635 | 0 |
| 530 | 1 |
| 520 | 2 |
| 482 | 3 |
| 469 | 4 |
| 441 | 5 |
| 401 | 6 |
| 399 | 7 |
| 352 | 8 |
| 368 | 9 |
| 339 | 10 |

**ALUMINUM**

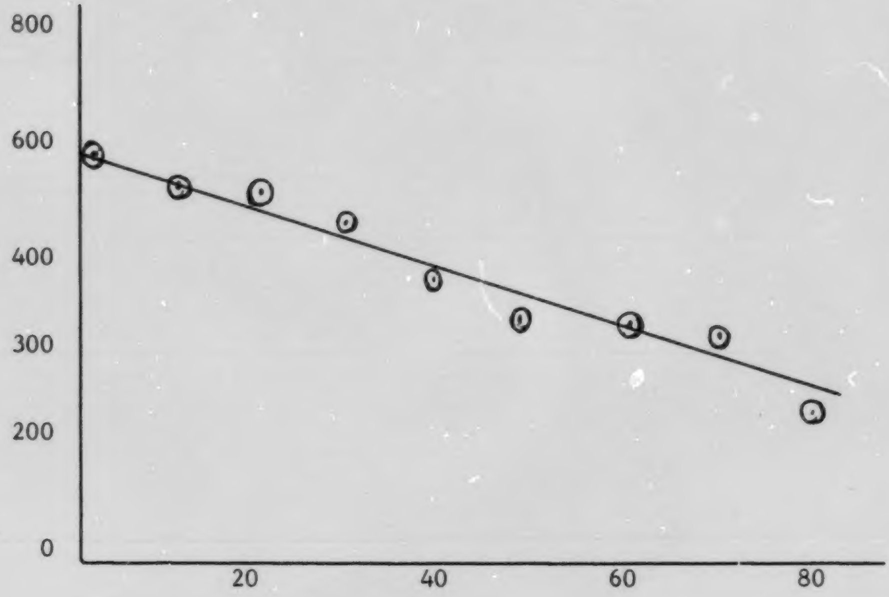
| c/m | NUMBER OF SHEETS |
|---|---|
| 585 | 0 |
| 529 | 10 |
| 502 | 20 |
| 458 | 30 |
| 391 | 40 |
| 340 | 50 |
| 332 | 60 |
| 309 | 70 |
| 251 | 80 |

LEAD



Number of Sheets

ALUMINUM



Number of Sheets

Q1 - Looking at the graphs, what do you conclude about lead as a shield as compared to aluminum?

A1 - Lead is a better shield.

Q2 - How many sheets of aluminum equal the shielding ability of 1 sheet of lead?

A2 - About 6.3.

Q3 - What thickness of aluminum would shield half the gamma radiation?

A3 - 70 sheets (70mm)

Q4 - How does this compare with the half thickness of aluminum for the beta radiation in the last experiment?

A4 - Much greater.

Q5 - What is the half thickness of lead for your gamma source?

A5 - 12 sheets (12 mm)

Q6 - How does this compare with the half thickness of lead for beta radiation in the last experiment?

A6 - Much greater.

Q7 - If you are using 6 sheets of aluminum in the experiment, does it make any difference whether they are close together or there are air spaces between them?

A7 - No.

Q8 - By extrapolating can you predict what thickness of lead would completely shield the source?

A8 - No. In theory it will never reach zero.

POSTLAB DISCUSSION:

Go over the questions. Include discussion of the summary at the bottom of page 93.

## EXPERIMENT 4-6: BACK SCATTERING

The purpose of this experiment is to show that radiation can be reflected.

OBJECTIVES:

Given a beta source, scaler, lead and aluminum shields, the student should discover whether beta radiation bounces back from the shields.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 40 minutes

Postlab - 15 minutes

MATERIALS:

PER GROUP - Radioactive disc (beta)
G-M tube and scaler
Timer
4 lead shields
1 aluminum shield
1 cardboard shield
Calibrated board

### ADVANCE PREPARATION:

None

### HINTS:

None

### PRELAB DISCUSSION:

Make sure they understand what they are attempting to do in the experiment. (Can radiation be reflected?)

### TYPICAL RESULTS:

NOTE: Group 1 are corrected counts.

| GROUP | BACKGROUND | SOURCE | CARDBOARD | ALUMINUM | LEAD |
|---|---|---|---|---|---|
| 1 | 266 | 40 | background | 13 | 212 |
| 2 | 114 | 130 | 120 | 121 | 177 |
| 3 | 137 | 117 | 149 | 144 | 238 |
| 4 | 94 | 100 | 118 | 110 | 121 |
| 5 | 146 | 135 | 153 | 187 | 206 |
| 6 | 105 | 120 | 154 | 170 | 266 |
| 7 | 155 | 145 | 153 | 169 | 215 |

Q1 - How do the readings from trials A and B compare?

A1 - About the same (A & B).

Q2 - Did radiation penetrate the lead partition?

A2 - No.

Q3 - How do the last three readings compare with the second?

A3 - Lead (E) much higher, than Aluminum (D) and cardboard (C).

Q4 - How can you explain the difference?

A4 - Beta radiation is reflected from the shield to the G-M tube. Also lead reflects better than aluminum or cardboard

Q5 - Do all the scattering shields affect the radiation in the same way?

A5 - No, lead is a much better reflector than aluminum or cardboard.

Q6 - From your data, which shield, if any, caused the most back scattering?

A6 - Lead.

POSTLAB DISCUSSION:

Put the class data on the board so that the students can use it to answer the questions. Go over any of the questions that they have trouble with.

## EXPERIMENT 4-7: COLLIMATION

The purpose of this experiment is to show that radiation can be focused.

OBJECTIVES:

Given a radioactive beta source, scaler, lead, aluminum and cardboard tubes the student should discover the relative scattering effect of each of these tubes on the beta radiation.

ESTIMATED TIME:

Prelab - 10 minutes

Experiment - 15 minutes

Postlab - 5 to 10 minutes

MATERIALS:

PER GROUP - Radioactive disc (beta)
G-M tube and scaler
Timer
Ringstand and buret clamp
Lead scattering tube
Aluminum scattering tube
Cardboard scattering tube

ADVANCE PREPARATION:

The scattering tubes will have to either be purchased from a supply house or they can be made. The lead tubes can be made from large lead sheets which can be forced around a cardboard mailing tube. The aluminum can be purchased as thick walled aluminum conduit and cut into lengths.

HINTS:

None

PRELAB DISCUSSION:

Discuss text material on page 95 Make sure they understand the problem and you may have to emphasize that they should keep the disc and the tube at the same distance throughout the experiment. They should also make sure that they center the disc and G-M tube for each trial.

TYPICAL RESULTS:

Corrected C/M

| GROUP | DISC (c/m) | Lead (c/m) | Aluminum (c/m) | Cardboard (c/m) |
|---|---|---|---|---|
| 1 | 1062 | 2294 | 1638 | 1398 |
| 2 | 265 | 488 | 435 | 324 |
| 3 | 239 | 394 | 376 | 272 |
| 4 | 1124 | 2234 | 1875 | 1506 |
| 5 | 1439 | 3039 | 2378 | 1842 |
| 6 | 1118 | 2174 | 1982 | 1409 |
| 7 | 372 | 581 | 475 | 376 |

Q1 - Which tube produced the greatest amount of collimation (scattering)?

A1 - Lead.

Q2 - What things determine the amount of scattering?

A2 - Type of material and greater density seems to scatter more.

Q3 - How is collimation related to back scattering?

A3 - In this case some of the reflecting particles are kept inside the tube as they bounced back and forth.

Q4 - With a G-M tube 8 cm from a radioactive source, how would you position a lead sheet and a lead tube to obtain the maximum count?

A4 - Put lead sheet under source and arrange the lead tube as shown in Figure 4-7.

POSTLAB DISCUSSION:

Post data on the board so that they have this available to answer the questions After they have handed in the experiment go over any questions that they had difficulty with.

## EXPERIMENT 4-8: AMOUNT OF RADIATION

The purpose of this experiment is to show that: (1) different quantities of radioactive materials have different amounts of activity, and (2) the activity of an arbitrary amount of radioactive material can be used to describe the activities of other materials. (Introduction to unit curie.)

### OBJECTIVES:

Given a scaler, and several sources of a given radioactive material the student shall record the count of each source, assume that the count of the least active source is a "unit of measurement", and compare the strength of the other sources by using this "unit of measurement".

### ESTIMATED TIME:

Prelab - 15 minutes

Experiment - 40 minutes

Postlab - 15 minutes

### MATERIALS:

PER CLASS - 7 samples labeled 1 - 7 (see advance preparation)
2 or 3 unknown samples (see advance preparation)

PER GROUP - G-M tube and scaler
Timer
Ringstand and buret clamp

### ADVANCE PREPARATION:

The samples may be made by dissolving uranyl acetate or uranyl nitrate in water. Use an eye dropper and add drops to a planchet. (Planchets with concentric rings work the best.) The samples are dried and counted. By careful addition of the drops one can get the samples to vary such that the second sample is twice the first, 3rd sample three times the first, etc. The unknown are prepared with the same materials and techniques. These samples can be used from year to year.

### HINTS:
None.

**PRELAB DISCUSSION:**

Discuss text material on page 97. Make sure that they understand that the same substance was used to prepare the samples The difference is in the amount of sample used

**TYPICAL RESULTS:**

| | Corrected c/m on each sample | | | | | | |
|---|---|---|---|---|---|---|---|
| GROUP | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 40 | 82 | 105 | 117 | | 227 | 267 |
| 2 | 52 | 84 | 116 | 187 | 213 | 226 | 244 |
| 3 | | | | | | | |
| 4 | 28 | 78 | 119 | 169 | 203 | 219 | 278 |
| 5 | | | | | | | |
| 6 | 63 | 80 | 112 | 283 | 197 | 208 | 302 |
| 7 | 43 | 102 | 113 | 198 | 232 | 266 | 300 |
| 8 | 27 | 61 | 122 | 168 | 185 | 214 | 261 |

Q1 - Which sample gave the highest count?

A1 - 7

Q2 - Which sample gave the lowest count?

A2 - 1

Q3 - Can you find any relationship among the counts? (Does the count double as you go from one to the next? Is it cut in half? Is there a common factor relationship?) Divide all counts by the lowest count and record in an added column.

A3 - Count/Low c/m

| GROUP | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 2.0 | 2.6 | 4.2 | 4.7 | 5.7 | 6.7 |
| 2 | 1.0 | 1.6 | 2.2 | 3.5 | 4.8 | 4.3 | 4.7 |
| 3 | 1.0 | 1.8 | 2.3 | 4.3 | 4.4 | 5.5 | 6.6 |
| 4 | 1.0 | 2.0 | 3.0 | 4.2 | 5.1 | 5.5 | 7.0 |
| 5 | 1.0 | 1.2 | 1.7 | 2.9 | 3.1 | 5.8 | 4.7 |
| 6 | 1.0 | 1.9 | 2.2 | 4.2 | 5.0 | 3.3 | 7.0 |

Q4 - How many eirucs of activity did each of the other samples have?

A4 - The activity in eirucs is the same as the above ratios.

Q5 - Suppose we had a sample with twice the activity of the least active sample. How many eirucs of activity would it have?

A5 - 2 eirucs.

Q6 - How many eirucs of activity would a sample contain if it were only half as active as the least active sample?

A6 - 0.5 eiruc.

Q7 - Express activity of the unknown in eirucs.

A7 - Depends upon activity of their unknown.

Q8 - Could you express the activity of any sample in eirucs?

A8 - Yes.

Q9 - Define an eiruc.

A9 - The activity of the reference source.

### POSTLAB DISCUSSION:

Post class data for the corrected count on each sample. The students can use this to answer Q1 and Q2. Also post Q3 the count/lowest count ratios for each sample. You can point out that even though the results vary significantly from group to group for the corrected count data that the ratio data is quite consistent.

## TEXT MATERIAL PAGE 100 & 101:

Have the students read this section and discuss as needed. The student should work Exercise 4-1.

## ANSWERS TO EXERCISE 4-1

a) $$\frac{3.7 \times 10^{4} \text{ d/s}}{3.7 \times 10^{10} \ \frac{\text{d/s}}{\text{curie}}} = 1.0 \times 10^{-6} \text{ curie}$$

b) $$\frac{1.0 \times 10^{-6} \text{ curie}}{10^{-6} \text{ curie/microcurie}} = 1 \text{ microcurie}$$

c) $$\frac{7.4 \times 10^{7} \text{ d/s}}{3.7 \times 10^{10} \text{ d/s/curie}} = 2.0 \times 10^{-3} \text{ curie}$$

$$\frac{2.0 \times 10^{-3} \text{ curie}}{10^{-6} \text{ curie/microcurie}} = 2.0 \times 10^{3} \text{ microcuries}$$

d) 20 microcuries initially, after 5 days it will be 10 microcuries, after 10 days it will be 5 microcuries, and after 15 days it will be 2.5 microcuries.

e) $2.5 \text{ microcuries} = 2.5 \times 10^{-10} \text{ curie}$

$$2.5 \times 10^{-6} \text{ curie} \times \frac{3.7 \times 10^{10} \text{ d/s}}{\text{curie}} = 9.3 \times 10^{4} \text{ d/s}$$

## EXPERIMENT 4-9: GEOMETRY OF RADIATION

The purpose of this experiment is to: (1) show that radiation travels in all directions, and (2) compare counts/minute read by the G-M tube scaler system with disintegrations per minute.

### OBJECTIVES:

Given a radiation sphere with a gamma source in its center, scaler and ruler, the student should observe that radiation travels in all directions from the source, that a G-M tube picks up only that radiation which enters the tube, and compare the count per minute reading with the total activity of a sample.

**ESTIMATED TIME:**

Prelab - 10 minutes

Experiment - 50 minutes

Calculator time - 25 minutes

Postlab - 20 minutes

**MATERIALS:**

PER GROUP - Radiation sphere
Scaler
G-M tube
Timer
Ruler

PER CLASS - Electronic calculator (if available)

**ADVANCE PREPARATION:**

See special materials.

**HINTS:**

None.

**PRELAB DISCUSSION:**

Very brief. Make sure they understand the problem and the procedure to be followed.

RESULTS - EXPERIMENT 34:

| No. of Sphere | Group | 1 | 2 | 3 | 4 | 5 | 6 | Ave. | Each Spot Ave. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 1 | 482 | 489 | 494 | 506 | 463 | 441 | 479 | 1.0 | 1.0 | 1.0 | 1.1 | 1.0 | .9 |
| 3 | 2 | 283 | 460 | 275 | 475 | 434 | 477 | 400 | .7 | 1.1 | .7 | 1.2 | 1.1 | 1.2 |
| 8 | 3 | 120 | 120 | 120 | 110 | 100 | 120 | 120 | 1.0 | 1.0 | 1.0 | .9 | .8 | 1.0 |
| 4 | 4 | 340 | 240 | 210 | 280 | 280 | 220 | 260 | 1.3 | .9 | .8 | 1.0 | 1.0 | .8 |
| 2 | 5 | 440 | 470 | 390 | 460 | 400 | 390 | 425 | 1.0 | 1.1 | .9 | 1.1 | .9 | .9 |
| 9 | 6 | 81 | 99 | 93 | 76 | 56 | 60 | 78 | 1.0 | 1.3 | 1.3 | 1.0 | .7 | .8 |
| 6 | 7 | 79 | 75 | 94 | 77 | 82 | 110 | 86 | 1.0 | 1.1 | .9 | 1.1 | 1.0 | .8 |

Q1 - How do these 6 readings compare?

A1 - Readings are all pretty close

Q2 - Do you think there would be any point on the sphere where the radiation would be significantly larger?

A2 - No

Q3 - Find the average of your 6 readings. Divide each reading by the average. How do your values compare with others in the class?

A3 - All close to 1.0.

Q4 - In what direction, or directions, is the radiation traveling from the source?

A4 - All directions.

Q5 - What do the results tell you about the amount of radiation as the direction changes?

A5 - Seem to be about the same.

Q6 - What does the amount of measured radiation depend on?

A6 -Distance from G-M tube, amount of radioactive material, half-life of radioactive material.

Q7 - Since radiation is moving out in all directions, how would it be possible to obtain a measure of the total radiation coming from the source?

A7 - One would have to count every end window area on the sphere and add them together.

Q8 - If the end window were four times larger, how would this affect the radiation counted?

A8 - Increase the count by 4 times.

Q9 - If the end window were 10 times larger, how would the radiation count be affected?

A9 - Increase the count by 10 times.

Q10 - How large would the area of the end window have to be in order that all the points on the sphere would be covered?

A10 - Area at least as large as the sphere. It would have to be a wrap-around type

Q11 - If you knew the area of the end window and total surface area of the radiation sphere, how could you determine the percent of radiation measured?

A11 - $\frac{\text{Area of G-M window}}{\text{Area of sphere}} \times 100\% = \%$ radiation measured

Q12 - What is the area of the end window on the G-M tube you used?

A12 - $A_{\text{window}} = \frac{3.14 \times (1.4)^2}{4} = 1.54 \text{ cm}^2$ (Diameter or our end window = 1.4 cm)

Q13 - The formula for the surface area of a sphere is: Area = $4\pi R^2$, where R is the radius of the sphere. What is the surface area of the radiation sphere you are using?

A13 - $S_{\text{area of sphere}} = (4)\ (3.14)\ (7.8)^2 = 760 \text{ cm}^2$ (for our spheres)

Q14 - What is the ratio of area of the end window to the surface area of the sphere?

A14 - $$\frac{A_{\text{window}}}{S_{\text{area sphere}}} \quad \frac{1.54\text{cm}^2}{760\text{cm}^2} = .002$$

Q15 - What is this fraction in percent?

A15 - 0.2%

Q16 - What percent of the radiation passing through the ball is the G-M tube measuring?

A16 - 0 2%

Q17 - Assuming the G-M tube is counting each particle or ray which enters it, how does the measured counts/minute (c/m) compare with the disintegrations/minute (d/m) of the source?

A17 - $$\frac{\text{Ave c/m}}{.002} = \frac{120}{.002} = \frac{120}{2 \times 10^{-3}} = 6 \times 10^4 \text{ d/m} = \frac{6 \times 10^4 \text{ d/}\cancel{m}}{6 \times 10^1 \text{ s/}\cancel{m}} = 1 \times 10^3 \text{ d/s}$$

Q 18 - Express the activity of the source in curies.

A18 - $$1 \times 10^3 \text{ d/s} \times \frac{1 \text{ curie}}{3.7 \times 10^{10} \text{ d/s}} = .27 \times 10^{-7} = 2.7 \times 10^{-8} \text{ curie}$$

Q19 - If your G-M tube detected $5 \times 10^{10}$ counts/minute at the surface of the sphere, express the approximate activities of the source in curies. (Again assume that each particle or ray which enters the G-M tube is counted.)

A19 - $\frac{5 \times 10^{10}\ \text{c/m}}{2 \times 10^{-3}} = 2.5 \times 10^{13}\ \text{d/m} \times \frac{1\text{m}}{60\text{s}} \times \frac{1\ \text{curie}}{3.7 \times 10^{10}\text{d/s}} = 11$ curies

### POSTLAB DISCUSSION:

Post group results on the board so that the students can use these to answer the questions. Discuss pages 105-109.

### ANSWERS TO EXERCISE 4-2:

(a) Gamma rays - 3 rem

Alpha particles - 15 (rbe) x 3 rads = 45 rem

(b) Alpha

(c) 2,2

### ANSWERS TO EXERCISE 4-3:

(a) (38-18) x 5 = 100 rem

(b) Since 10 rems per year is the maximum permissable dose and the person has already had 9, he would have to wait until January (can receive 1 rem in October)

(c) 10 rems (limited by skin dose)

(d) Class discussion

(e) Shielding, distance, time

## INTRODUCTION TO CHAPTER 5

Chapter 5 introduces the student to a little of the theory of nuclear radiation It is not intended to be a thorough exploration of nuclear theory. The use of mathematics is kept to a minimum. If the class is particularly advanced the teacher may wish to expand Chapter 5 using outside references.

The chapter begins with an expansion of the simple atomic model presented in Chapter 2. The concept of isotopes is explored and an experiment is performed to show that radioactive and non-radioactive isotopes of the same element react the same chemically.

The theory of radioactive decay is explored and the students learn to work through a radioactive decay series.

An experiment to separate radioisotopes follows.

The creation of man made isotopes precedes a discussion of fission and fusin. Particular emphasis is placed on these processes as energy sources.

## CHAPTER 5

Discuss pp. 110-111 and work Exercise 5-1.

### ANSWERS TO EXERCISE 5-1:

a. 17

b. 35, 36, 37

c. 17

d. same

e. isotopes (chlorine)

### EXPERIMENT 5-1: PRODUCTION OF INDIUM HYDROXIDE WITH AND WITHOUT RADIOACTIVE INDIUM

The purpose of this experiment is to show that radioactive isotopes and non-radioactive isotopes of the same element are chemically the same.

### OBJECTIVES:

Given non-radioactive and radioactive compounds which may react to form new compounds, the student will observe that the chemical behavior of the radioactive compound will be similar to its non-radioactive counterpart.

ESTIMATED TIME:

Prelab - 5 minutes

Experiment - 40 minutes

Postlab - 15 minutes

MATERIALS:

PER GROUP - G-M tube and scaler
- 2 test tubes 18 x 150 mm
- 1 graduate (10 or 25 ml)
- 1 beaker (25 or 50 ml)
- 1 funnel
- 2 index cards
- 2 sheets filter paper
- 1 forceps
- 1 safety tray & liner
- Plastic gloves

PER CLASS - $InCl_3$ solution non-radioactive (2ml/group)
- $NH_4OH$ solution (5ml/group)
- $Sn^{113}/In^{113}$ minigenerator

ADVANCE PREPARATION:

Indium Chloride solution: Add 1 ml of concentrated HCl (Hydrochloric acid) to 100 ml water. To this solution add 1 gram of Indium Chloride and mix.

Ammonium hydroxide solution: Add about 7 ml of concentrated ammonium hydroxide to 100 ml water and mix.

HINTS:

They will have to look carefully when adding the eluant from the minigenerator to see a precipitate

PRELAB DISCUSSION:

Discuss the introduction so that they know they are using the same element Indium in both parts of the experiment.

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**TYPICAL RESULTS:**

Results Exp. 35:

| | Group Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Part I: | | | | | | | | |
| Corrected C/M | | | | | | | | |
| | PPT | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Filtrate | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Part II: | | | | | | | | |
| | PPT | 410 | 6527 | 8500 | 3800 | 741 | 139 | 9050 |
| | Filtrate | 20 | 0 | 0 | 0 | 12 | 44 | 0 |

Q1 - What visible change took place when indium chloride was added to ammonium hydroxide?

A1 - White precipitate formed.

Q2 - Did any of the radioactive indium chemically combine to form a precipitate? How do you know?

A2 - Yes, the precipitate in the filter paper in Part II had a high count.

Q3 - Was there any radioactive indium that did not combine when the ammonium hydroxide was added to the solution? How do you know?

A3 - No, the filtrate in Part II was near background.

Q4 - Comparing the reaction in Part I to Part II, do you think that a radioactive isotope behaves similarly to a non-radioactive isotope? Did the indium hydroxide (the precipitate) appear to be the same in each case?

A4 - Yes, yes.

Q5 - In view of your answer to question 4, can you think of any practical applications of this technique?

A5 - Any type of a tracing technique where a radioactive isotope replaces a non-radioactive isotope.

**POSTLAB DISCUSSION:**

Post data on the board so that the students can use collective data to answer questions.

## MINIEXPERIMENT 5-2 - PAGE 114

The students will use techniques learned earlier to complete this experiment. Therefore no prelab discussion is necessary All they will need is their G-M tube and scalers, paper and lead shields. They should find alpha, beta, and gamma radiation present. The teacher will supply the uranium ore sample.

Discuss text on pages 114-115 and have students do Exercise 5-2 and 5-3.

## ANSWERS TO EXERCISE 5-2:

Complete the following table. You will have to use Appendix C to determine the names of the elements.

| Name of the Element | Atomic Weight | Type of Radiation Emitted | Number of Protons | Number of Neutrons | Half-life |
|---|---|---|---|---|---|
| Uranium | 238 | Alpha particle | 92<br>- 2 | 146<br>- 2 | 4.5 x $10^9$y |
| Thorium | 234 | Beta particle | 90<br>+ 1 | 144<br>- 1 | 24.1 d |
| Protactinium | 234 | Beta particle | 91<br>+ 1 | 143<br>- 1 | 1.17 m |
| Uranium | 234 | Alpha particle | 92<br>- 2 | 142<br>- 2 | 2.5 x $10^5$y |
| Thorium | 230 | Alpha particle | 90<br>- 2 | 140<br>- 2 | 8.0 x $10^4$y |
| Radium | 226 | Alpha particle | 88<br>- 2 | 138<br>- 2 | 1,620 y |
| Radon | 222 | $\alpha$ | 86<br>- 2 | 136<br>- 2 | 3.82 d |
| Polonium | 218 | Alpha particle | 84<br>- 2 | 134<br>- 2 | 3.05m |
| Lead | 214 | $\beta$ | 82<br>+ 1 | 132<br>- 1 | 26.8 m |
| Bismuth | 214 | Beta particle | 83<br>+ 1 | 131<br>- 1 | 19.7 m |
| Polonium | 214 | Alpha particle | 84<br>- 2 | 130<br>2 | 1.6 x $10^{-4}$s |
| Lead | 210 | Beta particle | 82<br>+ 1 | 128<br>- 1 | 19.4 y |
| Bismuth | 210 | $\beta$ | 83<br>+ 1 | 127<br>- 1 | 5.0 d |
| Polonium | 210 | Alpha particle | 84<br>- 2 | 126<br>- 2 | 138 d |
| Lead | 206 | Stable Atom | 82 | 124 | Stable |

Note that Lead 206 is stable and not radioactive, and we have reached the end of the line.

ANSWERS TO EXERCISE 5-3:

a. Mixture - All $^{238}U$ does not decay at the same time.

b. Polonium 210 has the shortest existence.

Uranium 234 has the longest existence.

c. Lead, bismuth, polonium.

Discuss text material on pages 117-118. Have students do Exercise 5-4.

ANSWER TO EXERCISE 5-4:

Because the daughter atoms emitted gamma radiation.

## EXPERIMENT 5-3: SEPARATION OF RADIOISOTOPES

The purpose of this experiment is to show that one of the daughter products of uranium (thorium) can be separated from an uranium compound.

### OBJECTIVES:

Given an uranium compound, the student is to separate thorium from the uranium by (1) solubility differences and (2) chromatography.

### ESTIMATED TIME:

Prelab - 20 minutes

Experiment - Part I - 40 minutes

Part II - 80 minutes (40 minutes on each of two days)

Postlab - 30 minutes

### MATERIALS:

PER GROUP - Planchets that will hold 1 ml
- G-M detection system
- Syringe pipette
- Heat lamp
- Hydrometer jar about 12" to 18" high and 2" in diameter
- Cork stopper to fit jar
- Common pin
- Centimeter ruler
- Safety tray and liner
- Plastic gloves

PER CLASS - Masking tape
Uranyl Nitrate (solid)
Uranyl Nitrate (saturated solution)
Ammonium Nitrate (saturated solution)
Ethyl Acetate
Graduated cylinder
2 pipettes, 1 ml
Separatory funnel, 100 ml
Test tube with stopper to fit
2 25 ml beakers
50% Hexane-Acetone by volume solution
Stirring rod
Whatman #1 chromatography paper 1" wide
1 ringstand with buret clamp

ADVANCE PREPARATION:

None.

HINTS:

Part II - Divide the saturated solution or uranyl nitrate into several beakers. Place beakers with a stirring rod in several convenient locations. Arrangements for the removal of chromatographs may be necessary since it may be beyond class time. If possible, the strip should be counted all in the same class period.

PRELAB DISCUSSION:

Discuss the procedure of Part I as you do steps A through E. While the student's samples for Part I are drying, discuss the procedures for Part II. While the chromatograph is hanging in the jar, discuss the method of counting the chromatograph strip.

TYPICAL RESULTS:

Part I:

| ACTIVITY OF SAMPLE IN WATER (c/m) | | ACTIVITY OF SAMPLE IN ETHYL ACETATE (c/m) | |
|---|---|---|---|
| No Shield | Paper Shield | No Shield | Paper Shield |
| 654 | 480 | 37 | 37 |

Q1 - Do either or both samples emit alpha?

A1 - Water appears to be emitting some alpha.

Q2 - Are either or both samples emitting primarily alpha?

A2 - No, but water is emitting some.

Q3 - Are either or both samples emitting other radiation?

A3 - Yes.

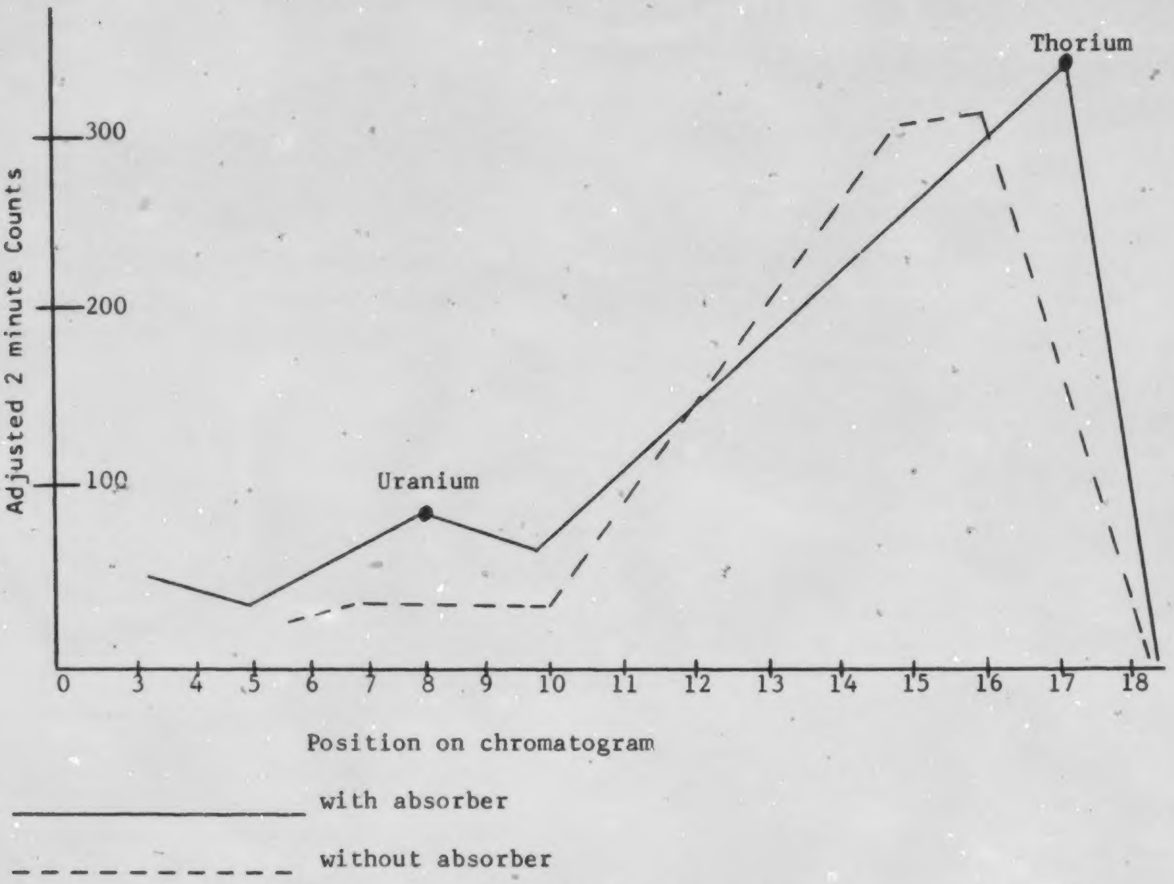
Q4 - Using the information from Figure 5-2, which sample contains thorium? Which sample has uranium?

A4 - Acetate - thorium.
Water - uranium.

TYPICAL RESULTS:

PART II:

| NO. ON PAPER | 2 MINUTE COUNT | ADJUSTED COUNT | ADJUSTED COUNT WITH PAPER ABSORBER |
|---|---|---|---|
| 3 | 89 | 41 | 46 |
| 4 | 87 | 39 | 27 |
| 5 | 82 | 34 | 33 |
| 6 | 91 | 43 | 28 |
| 7 | 102 | 54 | 48 |
| 8 | 128 | 80 | 49 |
| 9 | 115 | 67 | 36 |
| 10 | 112 | 64 | 36 |
| 11 | 135 | 87 | 59 |
| 12 | 155 | 107 | 87 |
| 13 | 199 | 151 | 131 |
| 14 | 255 | 207 | 201 |
| 15 | 271 | 223 | 245 |
| 16 | 270 | 222 | 246 |
| 17 | 306 | 258 | 229 |
| 18 | 219 | 171 | 131 |
| 19 | 119 | 71 | 74 |
| 20 | 48 | 0 | 3 |



Q1 - How many peaks do you find on your graph? Where are they located?

A1 - 2 peaks on each line; without absorber 8 and 17, with absorber 7 to 8 and 15 to 16.

Q2 - Are any of the peaks due to alpha emission? If so, where are they located?

A2 - Yes, about 7.5 and 15.5 positions.

Q3 - Are any of the peaks due to beta and/or gamma emission? If so where are they located?

A3 - Yes, best one at about 17.

Q4 - Mark the positions on your graph which represent the locations of Uranium-238 and thorium 234.

A4 - See graph.

Discuss text material pp. 124-128 and have students work Exercise 5-5.

ANSWERS TO EXERCISE 5-5:

a. Neutron and particle accelerators

b. No.

c. Put a low atomic weight substance such as paraffin between the G-M tube and the source.

Discuss text material pp. 128-134 and have the students work Exercise 5-6.

ANSWERS TO EXERCISE 5-6:

a. B, no.

b. Place substance in the reactor so that it will be bombarded with neutrons.

c. In the nuclear reactor the chain reaction is controlled while in the bomb reaction accelerates out of control. The nuclear reactor contains a critical mass while the bomb contains super-critical mass. They both make use of a chain reaction. They both give off heat. They both depend upon fission. They both give off radioactive by products, etc. When it melts down the surface area is increased allowing more neutrons to escape than are being produced, hence, the mass becomes sub-critical.

Discuss text material pp. 134-136, and have student work Exercise 5-7.

ANSWER TO EXERCISE 5-7:

Place small slice of paraffin between G-M tube and the source.

Discuss text material pp. 136-137.

## INTRODUCTION TO CHAPTER 6

Chapter 6 is an introduction to the three basic areas of applied nucleonics: Industrial, applied biology, and health services. The primary purpose of the chapter is to help the student decide which area he would like to explore in greater depth.

Since the techniques of tracing are used in all three areas, a tracing experiment is included in Chapter 6 and should precede any of the experiments from Chapters 7, 8, or 9.

## CHAPTER 6

Text pp. 138-141 - Have student read these pages. At this point, selected films (see film list) and/or outside speakers from the areas of application would be appropriate.

### EXPERIMENT 6-1: TRACERS

The purpose of this experiment is to introduce the technique of radioactive tracing which will be used in all three areas of application.

#### OBJECTIVES:

Given a tracer slab, radioactive disc and G-M tube, the student shall determine the location of the disc at various places in the slab.

#### ESTIMATED TIME:

Prelab - 10 minutes

Lab - 45 minutes

Postlab - 10 minutes

#### MATERIALS:

PER GROUP - G-M tube
Scaler or count rate meter
Radioactive disc (gamma)
Fish line or thread

#### ADVANCE PREPARATION:

Prepare tracer slabs. (See special materials section.)

HINTS:

None.

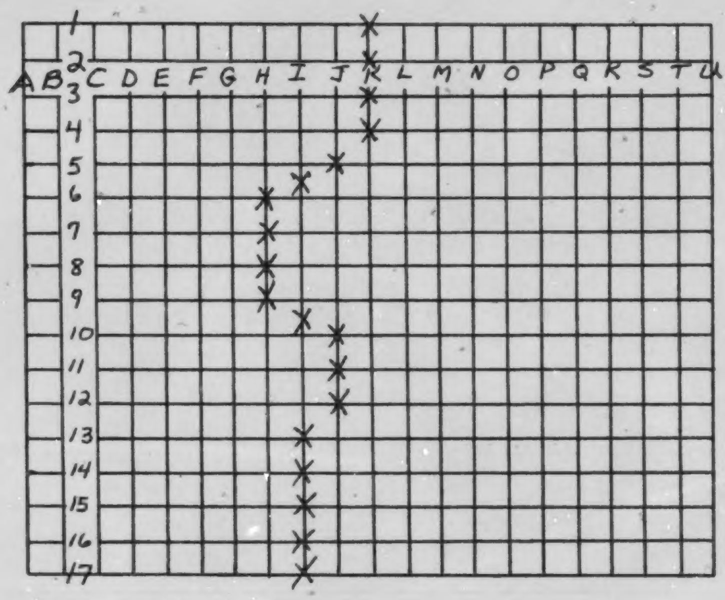
PRELAB DISCUSSION:

Discuss briefly what is meant by scanning. One minute counts aren't necessary, the student can watch the numbers and zero in on the "hot spot".

TYPICAL RESULTS:

Coordinate Locations

K-1
K-2
K-3
K-4
J-5
I-5.5
H-6
H-7
H-8
H-9
I-9.5
J-10
J-11
J-12
I-13
I-14
I-15
I-16
I-17



Q1 - Suggest some uses for tracers in industry.

A1 - Leak detection, flaw detection, flow rate.

Q2 - Suggest some uses for tracers in applied biology.

A2 - Fertilizer uptake, metabolism studies, photosynthesis studies.

Q3 - Suggest some uses for tracers in health services.

A3 - Thyroid disorders, tumor location, blood flow.

POSTLAB DISCUSSION:

Compare student grids and compile a list on the board of student answers to Q1 through Q3. This may help the student decide on an area of further study.

TEXT - PAGE 143:

Read over with class and discuss whether it is to be self-pacing Explain how equipment is to be distributed. Even if all chapters are to be covered in detail, you may wish to have students start at different points in Chapters 7 through 9. This will permit more efficient use of equipment.

## INTRODUCTION TO CHAPTERS 7-9:

Chapters 7 through 9 consist of a series of self-pacing experiments dealing with applications of nucleonics. The experiments (except as noted in experiment introductions) need not be done in sequence.

The main function of the teacher in these chapters is to answer questions and make sure equipment is available. The teacher may wish to hold periodic class discussions to exchange results if students are doing different experiments. It should be emphasized, to the student, that organization is important. The student should have the responsiblity of requesting equipment 2 or 3 days in advance of when it will be needed.

Some problems may arise concerning demand on equipment, particularly the Gammator. A sign-up sheet might become necessary to help solve this problem.

Because of the self-pacing concept of these three chapters, the format of the teacher's guide is changed somewhat:

1. Only experiments are discussed since there would normally be no class discussion.
2. The following sections are eliminated from experiment discussion: Estimated time, prelab discussion and postlab discussion.

In many cases a little postlab discussion would be desirable but it should be conducted on an individual or small group basis.

## CHAPTER 7 - INDUSTRIAL APPLICATIONS

### EXPERIMENT 7-1: DENSITY GAUGING

The purpose of this experiment is to determine variations in density of a model ingot and to apply this technique to flaw detection.

### OBJECTIVES:

Given a G-M tube, gamma source, and "ingot" of variable density, the student shall identify the positions where density varies along the "ingot".

## MATERIALS:

Scaler

Timer

G-M tube

Gamma source

Ingot of variable density

Graph paper

## ADVANCE PREPARATION:

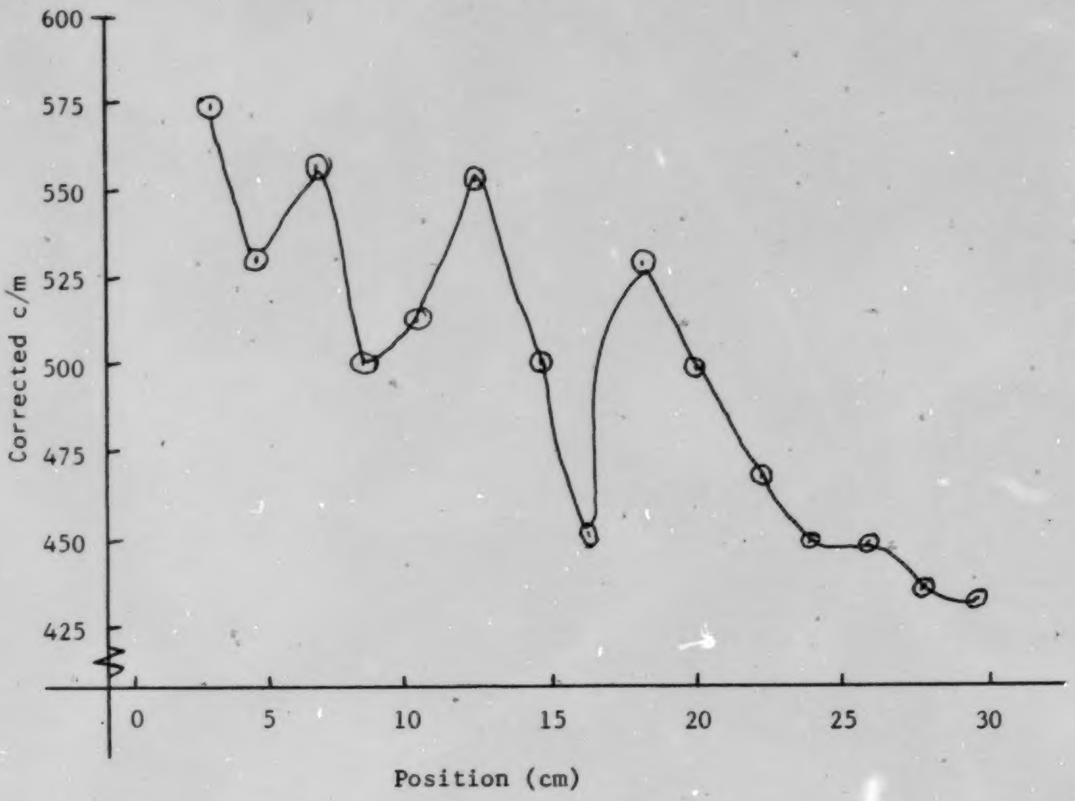
Prepare "ingots" - See special materials section.

## HINTS:

None.

## TYPICAL RESULTS:

| POSITION (cm) | C/M | CORRECTED (c/m) |
|---|---|---|
| 2 | 592 | 577 |
| 4 | 548 | 533 |
| 6 | 577 | 562 |
| 8 | 518 | 503 |
| 10 | 527 | 512 |
| 12 | 570 | 555 |
| 14 | 512 | 497 |
| 16 | 463 | 447 |
| 18 | 539 | 524 |
| 20 | 506 | 491 |
| 22 | 485 | 470 |
| 24 | 461 | 446 |
| 26 | 465 | 450 |
| 28 | 451 | 436 |
| 30 | 447 | 432 |



Q1 - How could you account for the shape of your graph?

A1 - Where the counts were high, the ingot must have had a low density, and vice-versa.

Q2 - How could the principle of this experiment be used to determine the water content of snow?

A2 - By the amount a source under the snow is shielded.

Q3 - In concrete, large stones and gravel are called aggregate. How would the principle of this experiment be used to demonstrate an even distribution of aggregate?

A3 - By putting source and G-M tube on opposite sides of the concrete and looking for fairly even count rate.

Q4 - How could the techniques of this lab be used to detect an air bubble in a solid casting?

A4 - By scanning the casting and looking for an area of high count (source and G-M tube on opposite sides of casting).

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## EXPERIMENT 7-2: THICKNESS GAUGING

The purpose of this experiment is to determine the thickness of a material by the amount of radiation transmitted through it.

### OBJECTIVES:

Given lead shields, gamma source and G-M tube, the student shall identify the unknown thickness of a group of shields by the count of the radiation passing through them.

### MATERIALS:

Scaler
10 lead shields
2 cardboard sheets
Gamma source
Timer
G-M tube
Centimeter ruler
Calibrated board

### ADVANCE PREPARATION:

Prepare an unknown by taping 3 or 4 sheets of lead between 2 sheets of cardboard. Arrange so student cannot count the lead sheet.

### HINTS:

None.

### TYPICAL RESULTS:

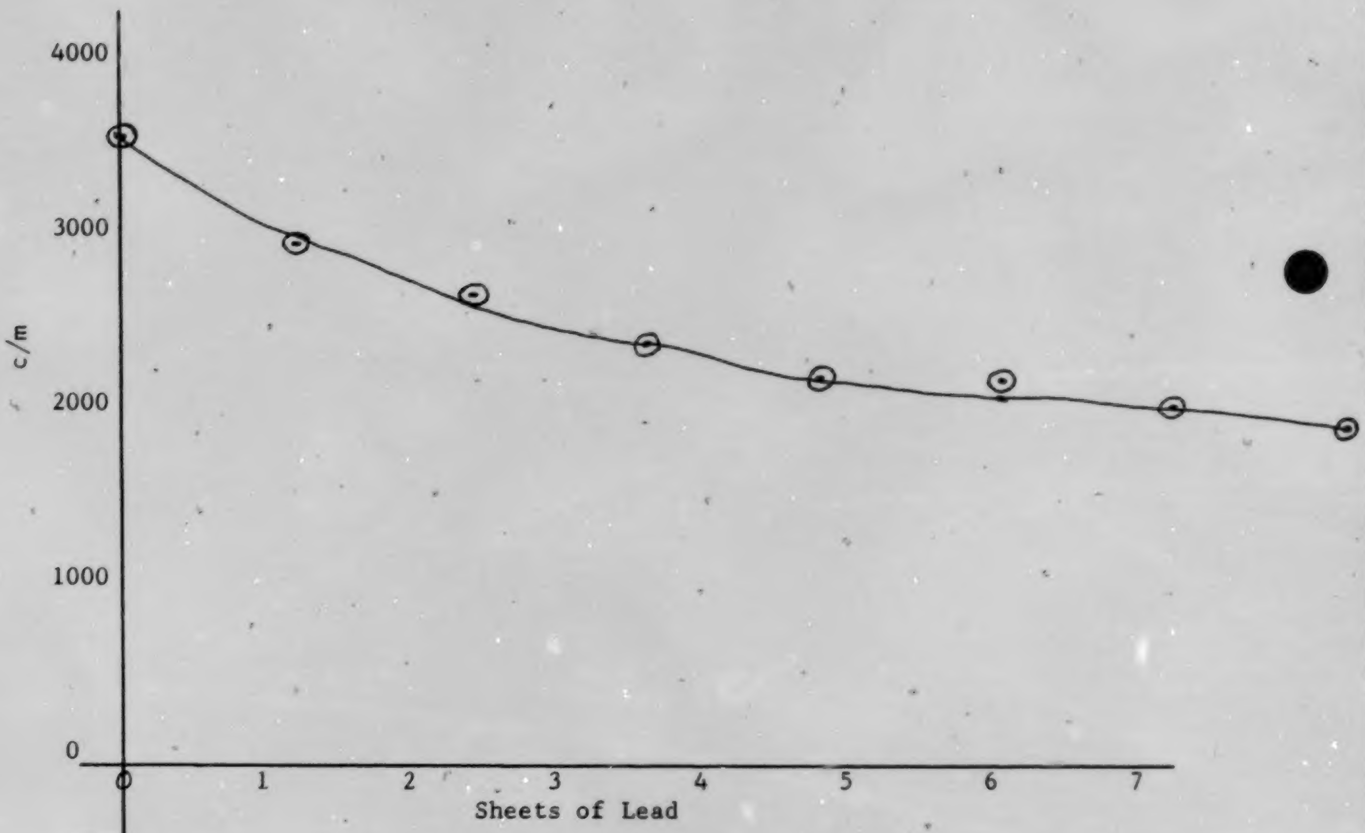
Q1 - What is the thickness of one sheet of lead?

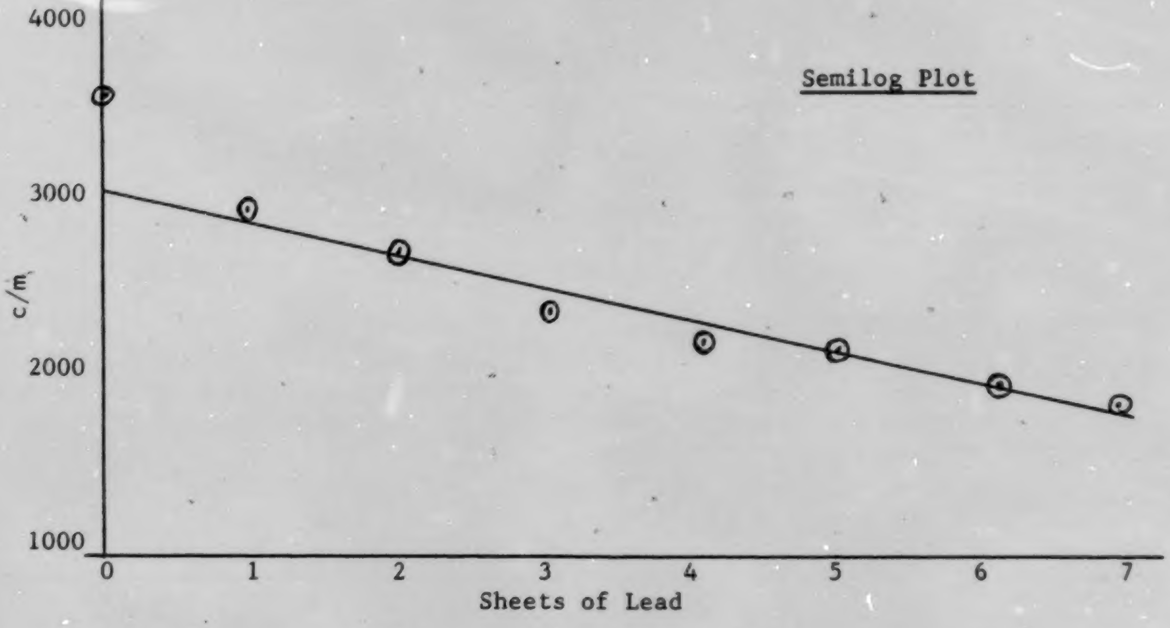
A1 - .82 mm.

Q2 - Why wasn't just 1 sheet measured rather than stacking 10 and dividing?

A2 - Because of the small thickness, the measurement of one sheet wouldn't be very accurate. The average of many sheets should be more exact

Count Rate vs Thickness





| SHEETS OF LEAD | CORRECTED C/M |
|---|---|
| 0 | 3512 |
| 1 | 2910 |
| 2 | 2623 |
| 3 | 2359 |
| 4 | 2178 |
| 5 | 2107 |
| 6 | 1996 |
| 7 | 1819 |

Q3 - What is the half thickness of lead for this radiation?

A3 - About 7 sheets of lead (about 57 mm).

Q4 - What purpose do you think was served by the original cardboard sheets?

A4 - Since the unknown was between cardboard sheets they were included in the original trials so the arrangement would be the same.

Q5 - From the graph and the count taken on the unknown, what is the thickness of the lead sheets?

A5 - Corrected count: 2390 - about 3 sheets (2.30 mm).

Q6 - What is the thickness as measured with a ruler?

A6 - 2.49 mm.

Q7 - By what percent do your two values of thickness differ?

A7 - 7.6%.

Q8 - How can the principle of this experiment be used in industry?

A8 - To measure thin or thick spots in metal sheets.

Q9 - Does this method require gamma radiation, or could beta be used? What qualifications would be needed?

A9 - The kind of radiation depends on the material being used. Beta could be used for thin materials or low density materials such as paper

Q10 - What advantages can you see in the radioactive gauging method.

A10 - Don't have to stop mill to measure. No contact so no wear. Can be arranged for automatic thickness control.

## EXPERIMENT 7-3: FLAW DETECTION

The purpose of this experiment is to model the X-ray technique for flaw detection.

### OBJECTIVES:

Given film, developer and objects to be "X-rayed", the student shall identify flaws in an object not naturally visible.

### MATERIALS:

Gammator

1 piece X-ray film (2" x 2½")

Developer and fixer for X-ray film

Objects to be "X-rayed"

Kodak Velox print paper (2½" x 3½") (F-3 or F-4)

Developer and fixer for print paper

Dark room

### ADVANCE PREPARATION:

Prepare film packets, objects to be "X-rayed" and developer and fixer (see special materials).

### HINTS:

Note that the developer and fixer for the X-ray film and the print paper are different.

### TYPICAL RESULTS:

Q1 - After the film has been developed, can you see any image on the film?

A1 - No - it is completely black.

Q2 - Since this is a film negative, what can you say about the exposure?

A2 - It is completely exposed.

Q3 - What does this tell you about the source in the Gammator?

A3 - Too strong for this film.

Q4 - How do the pieces of print paper compare?

A4 - On some papers a dark area shows what is apparently a flaw.

Q5 - If this is the case, which of the objects is flawless?

A5 - The one with uniform exposure.

Q6 - If flaws were present in any of the objects, describe or sketch their shape.

A6 - One contained an L shaped flaw and another contained an X shaped flaw.

## EXPERIMENT 7-4: STRAIN GAUGES

The purpose of this experiment is to demonstrate strain determination using radiation.

### OBJECTIVES:

Given a beta source, weights and rubber sheet, the student shall measure the degree of strain caused by a given weight.

### MATERIALS:

Radioactive source (beta)
3 ringstands
2 buret clamps
G-M tube and counting equipment
Rubber sheet (20 cm x 4 cm)
Weight hanger and weights
Support rod for rubber sheet
Centimeter ruler

### ADVANCE PREPARATION:

Prepare rubber sheet (cut from a rubber dam). See Figure 7-4 and lab instructions.

### HINTS:

None.

TYPICAL RESULTS:

Length - No weight = 12 cm

C/M - No weight = 7042

Corrected
c/m - No weight = 7023

| Weight on Hanger (gms.) | Length L (cm) | $\Delta$L Change in Length (cm) | Strain S | Counts/minute | Corrected Counts/Minute |
|---|---|---|---|---|---|
| 200 | 13.5 | 1.5 | .111 | 7108 | 7089 |
| 400 | 15.3 | 3.3 | 215 | 7263 | 7244 |
| 600 | 17.7 | 5.7 | .322 | 7284 | 7265 |
| 800 | 20.7 | 8.7 | .420 | 7272 | 7253 |
| 1000 | | | | | |

Q1 - Why does the count change as weight is added?

A1 - Because the rubber sheet becomes thinner.

Q2 - How could the strain on the drive belt on Figure 7-6 be determined for several speeds and load conditions?

A2 - By placing G-M tube and source on opposite sides of the drive belt, varying the speed and load and taking counts as in this experiment.

## EXPERIMENT 7-5: WEAR DETERMINATION

The purpose of this experiment is to use radioactive materials to determine wear differences.

### OBJECTIVES:

Given various objects, a weight, and a radioisotope, the student shall measure the ratio of wear among the various objects.

### MATERIALS:

G-M tube and counting equipment

Wooden block

Sandpaper

Cloth

Cardboard

Weight (1 kg.)

Heat Lamp

Minigenerator (Sr-90/Y-90)

Safety tray & liner

Plastic gloves

ADVANCE PREPARATION:

Cut sandpaper, cloth, and cardboard into strips 2" x 10". Cut wooden blocks into about 2" squares.

HINTS:

None.

TYPICAL RESULTS:

| MATERIAL | BACKGROUND | COUNTS AFTER WEAR ACTUAL | COUNTS AFTER WEAR CORRECTED |
|---|---|---|---|
| Cardboard | 18 | 51 | 33 |
| Sandpaper | 19 | 208 | 189 |
| Cloth | 22 | 27 | 5 |

Q1 - Which sheet showed the greatest increase in activity?

A1 - Sandpaper.

Q2 - Which sheet showed the least increase in activity?

A2 - Cloth.

Q3 - What is the ratio of wear caused by the sandpaper to that caused by the cardboard?

A3 - 5.8

Q4 - What is the ratio of wear caused by the cardboard to that caused by the cloth?

A4 - 6.6.

Q5 - Suppose a technician is testing methods of hardening drill bits. How could he use this technique?

A5 - By making the drill bit radioactive and measuring the radioactivity of the dust (or bit) after wear.

Q6 - Suppose a technician is testing the wear prevention ability of engine oils. How could he use this technique?

A6 - By making the piston rings radioactive and then draining the oil and checking its activity after use.

## EXPERIMENT 7-6: DETERGENT EFFICIENCY

The purpose of this experiment is to use radioisotopes to measure the cleansing efficiency of detergents

### OBJECTIVES:

Given various powdered detergents, oil, lamp black, an isotope and G-M tube, the student shall calculate the ratio of efficiency between the various detergents.

### MATERIALS:

G-M tube
Scaler
Heat lamp
Timer
Lamp black
Motor oil
100 ml beaker
Phosphorous-32 solution
4 different powdered detergents
4 1" squares of cotton cloth
Forceps
Wood splints
4 small bottles with screw caps
4 watch glasses
Safety tray
Plastic gloves
1 ml pipette & syringe

## ADVANCE PREPARATION:

Be sure $^{32}P$ is ordered in advance, a week or more. Acquire detergents early.

## HINTS:

None.

## TYPICAL RESULTS:

| DETERGENT BRAND | CORRECTED COUNTS UNWASHED COUNT | WASHED COUNT |
|---|---|---|
| A | 1209 | 842 |
| B | 1254 | 758 |
| C | 1196 | 649 |
| D | | |
| E | | |

Q1 - Was the change in the count the same for each detergent?

A1 - No.

Q2 - Was one obviously better than the others?

A2 - Two showed better cleansing ability than the others.

Q3 - Was one obviously poorer than the others?

A3 - Depends upon results.

Q4 - What particular ingredient was cleansed from the cloth?

A4 - The soil.

## EXPERIMENT 7-7: FLOW RATE OF FLUIDS

The purpose of this experiment is to determine the flow rate of a liquid using a radioisotope.

## OBJECTIVES:

Given tubing, G-M tube, water, source and isotope, the student shall measure the rate of the flow in the tube and calculate the volume of a specific section of a tubing.

## MATERIALS:

- 2½ meters of small diameter tubing
- Scaler of count rate meter
- G-M tube
- T-joint
- Plastic squeeze bottle
- Minigenerator Cs 137/Ba 137m
- Beaker (250 ml)
- Graduated cylinder (50 ml)
- Stopwatch
- Centimeter ruler

## ADVANCE PREPARATION:

None.

## HINTS:

Radioactive material should be injected as a burst rather than a stream. This experiment may have to be repeated so the students learn to coordinate their efforts.

## TYPICAL RESULTS:

Tubing Inside Diameter = 0.5 cm

Tubing Length = 200 cm

Time from Injection to end = 10 sec.

### VOLUME DETERMINATIONS

| Calculated From Tube Dimensions | Volume of Water Collected in Beaker | Volume of Water Delivered to Beaker over Timed Interval |
|---|---|---|
| 39 $cm^3$ | 45 $cm^3$ | 46 $cm^3$ |

Q1 - What is the volume of the tube between the T-joint and the detector?

A1 - 39 $cm^3$.

Q2 - Calculate how much water should have run into the beaker during the time the stopwatch was running.

A2 - 39 $cm^3$.

Q3 - Do the three measures of volume seem to agree?

A3 - Yes, fairly close within about 10%.

Q4 - What are the major sources of error in this experiment?

A4 - Time, dimension measure, time of maximum count, isotope dilution.

Q5 - How might the pipeline industry use the principles involved in this experiment?

A5 - Radioisotope injections can indicate the end of one company's supply and the start of another.

EXPERIMENT 7-8: DETERMINATION OF LIQUID VOLUME IN A CONTAINER

The purpose of this experiment is to use the dilution technique to determine the unknown volume of a liquid.

OBJECTIVES:

Given a container, unknown sample of liquid, G-M tube and radioisotope, the student shall calculate the liquid volume in a container and compare the volume calculated with the isotope to that measured in a graduated cylinder.

MATERIALS:

Scaler
G-M tube
Small vial
Stirring rod
Syringe and needle
Graduated cylinder (50 ml)
Minigenerator Sn 113/In 113
Unknown sample

ADVANCE PREPARATION:

Prepare an "unknown" volume. Keep this volume small (25-30 ml)

HINTS:

If the liquid volume is too large, the dilution will be so great that sample counts will be meaningless.

## TYPICAL RESULTS:

Background count = 44 c/m

Injection count (corrected) = 1063 c/m

Sample count (corrected) = 1019 c/m

Q1 - How much of the original radioisotope remains in the vial?

A1 - Half is left

Q2 - What corrected count would you expect if you checked this sample?

A2 - Half the original.

Measured count to check prediction = 500 c/m.

Q3 - Does the proportion work for the samples just measured?

A3 - Yes

Corrected count - 2 ml of eluant = 242

Corrected count - 2 ml dilution sample = 55

Volume of unknown (calculated) $= \frac{V_1A_1}{A_2} = \frac{(242)\ (2)}{55} = 9.8$ ml

Measured volume (with graduate) = 10 ml

Q4 - How close was your prediction?

A4 - About 1 ml.

Q5 - What is the volume of the oil in the tank?

A5 - 200 l including the added liter.

Q6 - How could the methods of this experiment be used to solve the doctor's problem?

A6 - Inject a patient with a known volume and activity of radioisotope. After ciruclation, withdraw the same volume from the patient. Calculate total volume.

## EXPERIMENT 7-9: LIQUID LEVEL

The purpose of this experiment is to determine liquid level using gauging techniques.

### OBJECTIVES:

Given a G-M tube, radioactive source, an open container, and a sealed tube containing unknown liquid levels, the student shall determine the level of the liquid in the two containers.

### MATERIALS:

G-M tube and counting equipment

150 ml beaker

Radioactive source (gamma - .5   Cesium 137)

Sealed tube - contents not exposed

### ADVANCE PREPARATION:

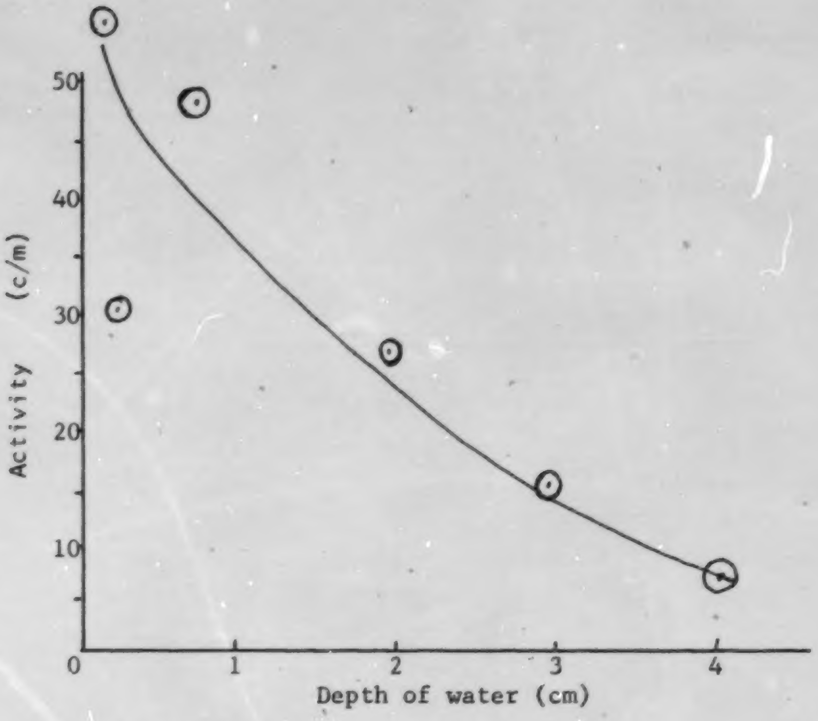
Prepare the sealed tube   Example: A stoppered 25 x 200 mm test tube, 3/4 full, wrapped so the contents cannot be seen.  .5  cesium source is needed.

### HINTS:

Part IV liquid level may be determined by placing G-M tube and radioactive sample on opposite sides of the tube. Do not reveal this technique to the student directly.

### TYPICAL RESULTS - Part I

| Water Depth (Centimeters) | Counts/Minutes | Corrected Counts/Minutes |
|---|---|---|
| 0 | 73 | 57 |
| .5 | 46 | 30 |
| 1 | 64 | 48 |
| 1.5 | 38 | 23 |
| 2 | 35 | 22 |
| 2.5 | 29 | 19 |
| 3 | 25 | 13 |
| 3.5 |  | 9 |
| 4 | 21 | 5 |



Q1 - What would the count/minute reading be if the water depth were 3.8 cm?

A1 - 7.

Q2 - What would the count/minute reading be if the water depth were 6 cm?

A2 - Very near background.

Q3 - What other information would be needed to determine the volume of the liquid in the container?

A3 - The diameter of the container.

Q4 - Could the graph prepared in this experiment be used to determine the depth of a brine solution? Explain

A4 - No. The shielding characteristics of brine may be different from the water used.

TYPICAL RESULTS: Part II

Q5 - Describe the method you devised for level determination.

A5 - The G-M tube and source were on opposite sides of "unknown". Move the sample and G-M tube up the unknown until the count increases.

Q6 - Describe how your method might be used in industry.

A6 - The G-M tube and source were on opposite sides of "unknown". Move the sample and G-M tube up the unknown until the counts increase.

## EXPERIMENT 7-10: POLYMERIZATION

The purpose of this experiment is to demonstrate that radiation can change a liquid to a solid showing polymerization.

### OBJECTIVES:

Given Methyl Methacrylate, container and Gammator, the student shall observe that radiation has the ability to change some liquids to solids.

### MATERIALS:

Gammator
Methyl Methacrylate
5 glass vials with plastic caps
5 watch glasses
Acetone

### ADVANCE PREPARATION:

None.

### HINTS:

None.

### TYPICAL RESULTS:

| VIAL # | IRRADIATION TIME (hrs.) | DOSE IN ROENTGENS | RESULT |
|---|---|---|---|
| 1 | 0 | 0 | Clear liquid |
| 2 | 6 | 100,000 | Some solid in watch glass |
| 3 | 24 | 720,000 | Firm but soft solid |
| 4 | 30 | 900,000 | |
| 5 | 48 | 1,440,000 | Very hard clear solid |

Q1 - Is there a solid on any watch glass after evaporation? If so, which one(s)?

A1 - Small amount in #2.

Q2 - Is there a solid in any vial after evaporation? If so, which one(s)?

A2 - Yes, 24, 30, and 48 hour exposure. (Perhaps 6)

Q3 - How did the amount of radiation affect the quantity of solid formed?

A3 - More radiation - more solid until all is solid.

Q4 - Within what irradiation range was a solid formed?

A4 - Above 180 kr.

Q5 - What evidence is there to indicate that the solid resulted from radiation and not evaporation?

A5 - 0 exposure remained liquid. The evaporated control left no residue.

## EXPERIMENT 7-11: PLASTICIZING WOOD

The purpose of this experiment is to demonstrate the use of gamma radiation to combine wood and plastic.

### OBJECTIVES:

Given various samples of wood, Gammator and Methyl Methacrylate, the student should observe a practical application of liquids turning to solids, by plasticizing samples of wood.

### MATERIALS:

Gammator
Methyl Methacrylate
4 wood samples (2 soft & 2 hard) about 1 $cm^3$
Plastic bag
Aluminum foil
Fine sandpaper
Filtering flask
Separatory funnel
1 hole rubber stopper to fit filtering flask and separatory funnel
Test tube to fit inside filtering flask
Aspirator
Vacuum hose

Heat lamp or drying oven
Ringstand and buret clamp
Weight to fit inside test tube
Screw type hose clamp

## ADVANCE PREPARATION:

None.

## HINTS:

After adding methyl methacrylate one will get better results if the pressure is increased above atmospheric.

## TYPICAL RESULTS:

Q1 - Rub the treated and untreated pieces of wood with sandpaper. How is the effect of the sandpaper different on the two blocks?

A1 - Sandpaper doesn't work as well as on the control.

Q2 - Which of the two blocks would be polishable?

A2 - Treated.

Q3 - Which block has the greater mechanical strength?

A3 - Treated seems harder to break.

Q4 - Which is harder and more scratch resistant?

A4 - Treated.

Q5 - Did the liquid seem to completely penetrate the wood samples?

A5 - Yes (will depend upon thickness of wood used).

Q6 - What was the purpose of the vacuum system?

A6 - Get all water out of wood pores.

Q7 - Suggest a practical application of this process.

A7 - Used to make wood flooring, furniture, etc., where one wants something hard with a permanent shine.

## EXPERIMENT 7-12: ATMOSPHERIC CONTAMINATION

The purpose of this experiment is to attempt to identify atmospheric radioactive materials by determination of half-life and use of nuclide tables.

### OBJECTIVES:

Given a tank type vacuum cleaner, filter paper and G-M tube, the student shall measure the amount of radiation in the air and identify the probable radiation source by calculating half-life, and comparing results with half-life tables

### MATERIALS:

- G-M tube
- Scaler
- High volume air sampler or tank type vacuum cleaner
- 3 x 3 wire screen
- Filter paper
- Ringstand and buret clamp

### ADVANCE PREPARATION:

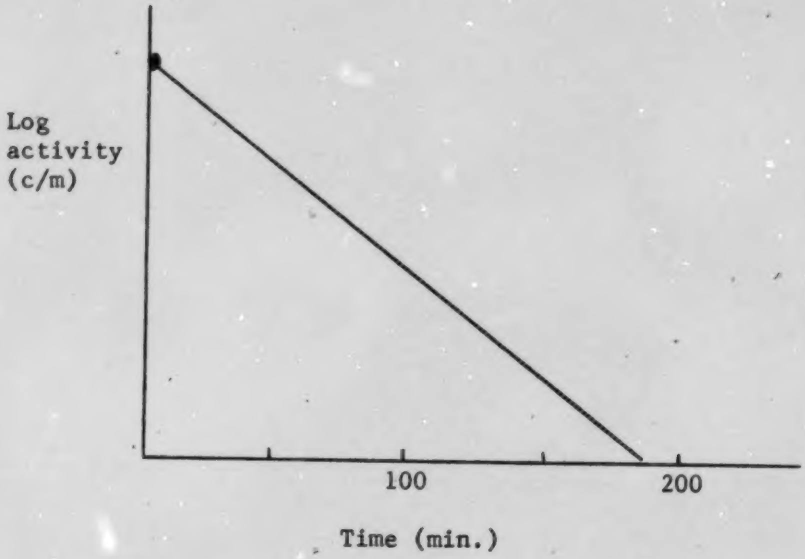
Start air sampler about 1 hour before class.

### HINTS:

Check closely. Our radioactive material may be peculiar to our community. Could ask students to determine which type(s) of radiation (alpha, beta, gamma) are being emitted from the sample. When we did this experiment in the summer we had a half-life of 30 minutes. This spring the students found a half-life of about 100 minutes. Thus the answers to the question will depend upon your data.

## TYPICAL RESULTS:

| TIME (min.) | CORRECTED COUNT c/m |
|---|---|
| 0 | 57 |
| 20 | 53 |
| 70 | 37 |
| 110 | 20 |
| 170 | 18 |



Semi log plot

Q1 - What is the half-life of the substance on the dirty filter paper?

A1 - About 100 minutes.

Q2 - Refer to Appendix D Could the substance be uranium 238, strontium 90, or carbon 14? Explain your answer.

A2 - No, the half-life was too short.

Q4 - Which of the Appendix D materials could it be?

A4 - Indium (the only substance in our table near 100 minutes).

## EXPERIMENT 8-1: NUCLEAR CLOCKS

The purpose of this experiment is to model radioactive dating

### OBJECTIVES:

Given an isotope, G-M tube, and an unknown sample, the student shall identify the time the teacher eluted the isotope. Given the results of the above objective, the student shall adapt this procedure to the technique of dating organic objects of great age.

### MATERIALS:

Cesium-137/Barium-$137^m$ minigenerator

2 planchets

Scaler, G-M tube and timer

Clock with sweep second hand

Sheet of semi-log paper

Safety tray and liner

Ringstand and buret clamp

Plastic gloves

Unknown sample prepared by instructor

### ADVANCE PREPARATION:

None.

### HINTS:

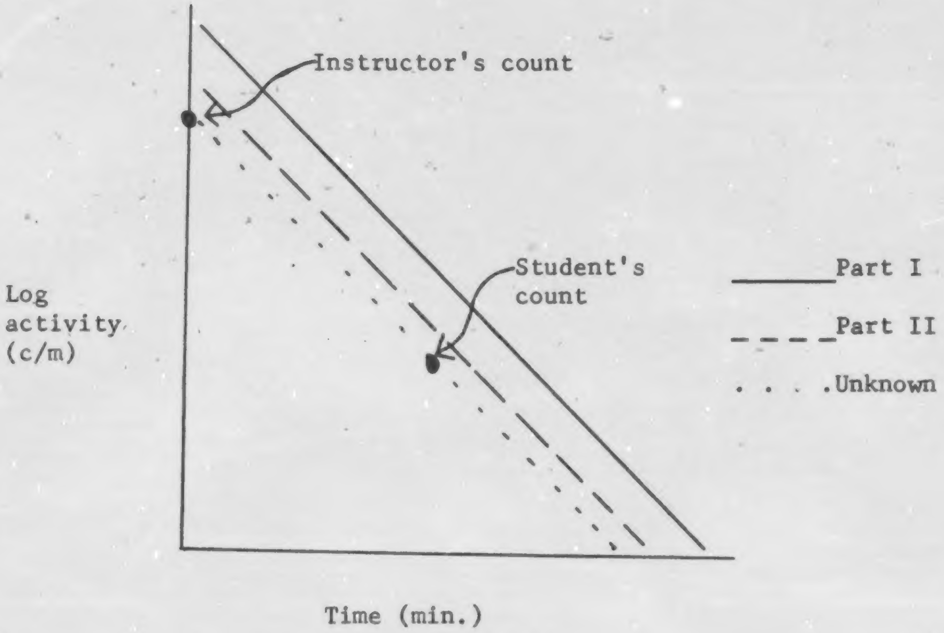
The "unknown" should be made up a few minutes before the students use it. The time and initial count of the "unknown" must be taken by the teacher as quickly as possible.

HINTS:

Make sure the instructor's count is taken with the G-M tube that the students use so the geometry will be the same.

TYPICAL RESULTS:

| TIME (min.) | c/m | Corrected c/m |
|---|---|---|
| 0.5 | 7473 | 7453 |
| 2.5 | 4730 | 4710 |
| 4.5 | 2662 | 2642 |
| 6.5 | | |
| 8.5 | | |
| 10.5 | | |
| 12.5 | | |
| 14.5 | | |



PART II

| TIME (min.) | c/m | Corrected c/m |
|---|---|---|
| .5 | 5679 | 5659 |
| 4.5 | 1443 | 1423 |
| 8.5 | 387 | 367 |

Q1 - How do the two lines on your graph compare?

A1 - They are parallel.

Q2 - If you would take three counts on another sample of the same material and plot on your graph paper, how do you think this line would compare with the other two?

A2 - It would be parallel.

Instructor's count on unknown = 4284 c/m
Count taken = 538 c/m
Time taken = 12:35

Q3 - How do you think the line for this plot would extend from this point?

A3 - Parallel with the other lines.

Q4 - How much time elapsed between the original elution and this point?

A4 - 9.5 minutes.

Q5 - Using your graph and the time you took your count, determine when you think your instructor eluted the minigenerator into the planchet.

A5 - 12:25 or 12:26.

Q6 - Ask your instructor and then record the time when the minigenerator actually was eluted.

A6 - 12:25.

Q7 - How does your prediction compare with the actual time of elution?

A7 - Very close, within a half of a minute.

Q8 - How long ago did the piece of wood grow?

A8 - 11,400 years.

## EXPERIMENT 8-2: FOOD PRESERVATION BY IRRADIATION

The purpose of this experiment is to demonstrate the use of radiation to extend storage time of bread.

### OBJECTIVES:

Given bread and a Gammator, the student shall identify the amount of radiation to pasteurize or sterilize food, and from this experience, perceive the economic applications.

MATERIALS:

3 slices of bread

Clear plastic sandwich bags with fold lock top

Label tape

Gammator

ADVANCE PREPARATION:

None.

HINTS:

Be sure the plastic bags are tightly sealed. Tape may be needed.

TYPICAL RESULTS:

Q1 - How did the bread irradiated for 24 hours compare with the control? How did the bread irradiated for 72 hours compare with the control?

A1 - Mold growth was great on the control, slight on the 24 hour sample, and none on the 72 hour sample.

Q2 - Compare the bread irradiated for 24 hours with the bread irradiated for 72 hours

A2 - The 24 hour sample had some mold. The 72 hour sample had none.

Q3 - Would the bread which was irradiated 72 hours be safe to eat?

A3 - Yes, from an irradiation point of view.

Q4 - What foods do you know of which are pasteurized? What method is used?

A4 - Milk - heat.

Q5 - Can you think of places where radiation pasteurization or sterilization might be used?

A5 - Any application where heat might be damaging.

EXPERIMENT 8-3: GROWTH INHIBITION

The purpose of this experiment is to demonstrate that radiation can be used to prevent sprouting and extend food storage time.

OBJECTIVES:

Given onions, and Gammator, the student shall observe that radiation inhibits growth, and from this observation, perceive ways by which this process may have economic significance.

MATERIALS:

- Gammator
- 6 onions
- 6 beakers
- Round toothpicks

ADVANCE PREPARATION:

None.

HINTS:

Be sure the onions have not been treated to inhibit growth. If onions cannot be found, small lily bulbs give good results.

Quantitative (various times of exposure versus root length) analysis would be a good special project.

TYPICAL RESULTS:

Q1 - Describe differences (if any) in the root tip development of each group.

A1 - Control growth was "normal". Irradiated group showed none.

Q2 - Would either group grow into plants which are radioactive?

A2 - No.

Q3 - Describe how this system could be used to extend the storage time of onions. Would onions treated this way be radioactive?

A3 - Onions could be irradiated after harvesting. They would keep longer and would not be radioactive.

## EXPERIMENT 8-4: DIFFUSION

The purpose of this experiment is to use radioisotopes as tracers to demonstrate diffusion.

OBJECTIVES:

Given an isotope, a liquid, dialysis tubing, and G-M tube, the student shall determine that the isotope does travel through the tubing, and perceive how such a process can aid a living cell to deposit waste and take in food.

MATERIALS:

G-M tube, scaler and timer

Minigenerator Sr-90/Y90

Dialysis tubing (size 36, 1 1/8" diameter) 15 cm long

Ringstand and clamp

Tray and liner

2 pipettes (1 ml) with propipetter

2 beakers (15 ml)

Rubber bands

Beaker (100 ml)

Graph paper

Plastic ring that will fit the dialysis tubing

ADVANCE PREPARATION:

Obtain a plastic bottle with a cap about 1½" in diameter. Remove the cap and cut the threaded portion from the bottle. This will serve as the plastic ring. (See Figure 8-3.)

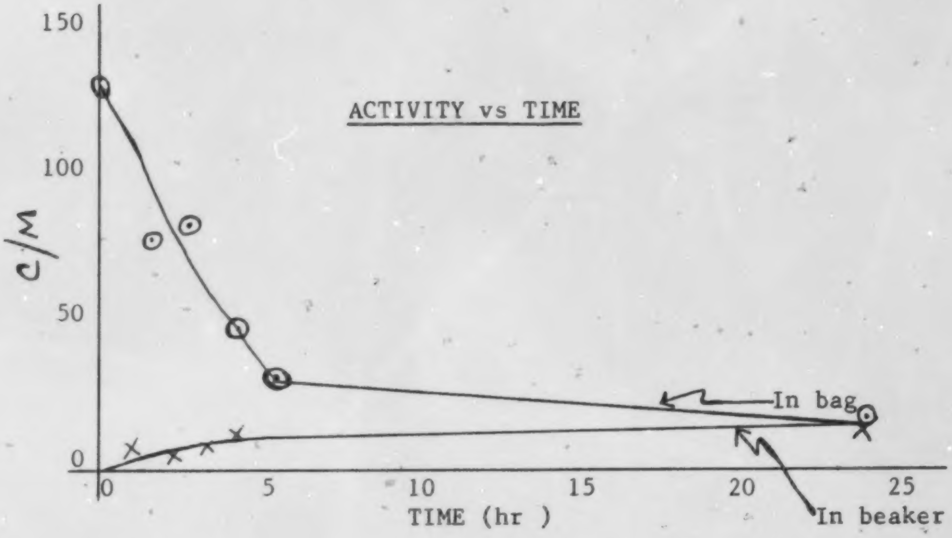
HINTS:

None.

TYPICAL RESULTS:

Background: 16 c/m

| Time | Elapsed time (hrs.) | Solution in Bag |  | Solution in Beaker |  |
|---|---|---|---|---|---|
|  |  | Activity (c/m) | Corrected (c/m) | Activity (c/m) | Corrected (c/m) |
| 10:55 |  | 138 | 122 | 15 | 0 |
| 11:55 | 1:00 | 92 | 76 | 23 | 7 |
| 12:55 | 2:00 | 94 | 78 | 23 | 7 |
| 1:55 | 3:00 | 65 | 45 | 25 | 9 |
| 2:55 | 4:00 | 55 | 39 | 27 | 11 |
|  | 24:00 | 36 | 20 | 33 | 17 |



Q1 - Did Yttrium-90 pass through the membrane? How do you know?

A1 - Yes. The count outside the bag increased.

Q2 - Which solution had the greatest initial concentration of Yttrium - that inside the bag or outside the bag?

A2 - Inside.

Q3 - Did all of the Yttrium-90 pass through the membrane? How do you know?

A3 - No. The count remained well above background inside the bag.

Q4 - Compare your two curves. Predict how the activity of the two solutions would compare after a long period of time.

A4 - One curve is increasing, the other is decreasing. Eventually the two activities will be the same.

Q5 - What do you think is happening to the concentration of the two solutions as the experiment proceeds?

A5 - They are becoming equal.

Q6 - Assume that the contents of the outer container were replaced with distilled water each time samples were taken. What would happen?

A6 - Both sections would approach zero activity.

Q7 - Propose a hypothesis concerning the structure of the dialysis tubing to explain the passage of the radioactive molecules through it.

A7 - Must have small holes, large enough to pass molecules.

Q8 - Considering that molecules are in constant motion, your model of the tubing in Q7, and your answer to Q4, why does the concentration of Yttrium reach a point where it stays the same on both sides of the tubing?

A8 - Equilibrium is reached where as many molecules of the Yttrium compound pass one way as the other.

Q9 - List several conditions that would tend to increase the amount of diffusion taking place through a membrane.

A9 - Bigger holes, greater concentration difference.

Q10 - If our model of the cell is correct, how can the cell get oxygen, food and remove its wastes?

A10 - By diffusion.

Q11 - Which organ of the body has a moist surface, large area, and thin membranes that would allow oxygen and carbon dioxide diffusion to take place?

A11 - The lungs.

## EXPERIMENT 8-5: THE UPTAKE OF CARBON-14 IN A VERIGATED LEAF

The purpose of this experiment is to show that carbon dioxide is utilized primarily in the green portion of the leaf and that the plant removes carbon dioxide from the air and incorporates it into its structure.

OBJECTIVES:

Given a coleus plant$^{14}C$ in sodium carbonate, G-M tube and film, the student shall discover that carbon is found in the leaf in the region of photosynthetic activity, and will surmise that the carbon taken into the plant is chemically bound in sugar, the end product of photosynthesis.

MATERIALS:

Sodium carbonate containing carbon-14

Plant with verigated leaves (coleus)
G-M tube and scaler
X-ray film

Developer
Fixer

Syringe

Clear plastic bag large enough to hold the plant
Dilute sulfuric or hydrocholoric acid

2 eye droppers
Small dish (00 crucible)

Ringstand and buret clamp
150 w bulb

Sodium hydroxide solution
Calcium hydroxide solution

Rubber tubing to fit 6 mm glass tubing
Glass tubing (6 mm)

Screw clamp
Aspirator

Scotch tape
Plastic gloves

Electrician's tape
Safety tray and liner

2 hole rubber stopper (6½ or 7)
4 short armed, right angle bent glass tubes
2 long armed, right angle bent glass tubes
Glycerine
Rubber band
3 250 ml erlenmeyer flasks with 2 hole stoppers to fit

### ADVANCE PREPARATION:

Be sure the carbon-14 is ordered in advance.

### HINTS:

None.

### TYPICAL RESULTS:

Q1 - What did you observe when the acid mixed with the sodium carbonate?

A1 - A little fizzing.

Q2 - What gas do you think is given off in this reaction?

A2 - Carbon dioxide.

Q3 - Was any carbon dioxide left when the bubbles reached the third flask?

A3 - No, limewater didn't turn cloudy.

Q4 - Why didn't we just open the bag and take the plant out?

A4 - It might release radioactive carbon dioxide into the air.

Q5 - Could you observe any radioactivity?

A5 - Yes, the green portion of the leaf showed a higher count than the non-green portion.

Q6 - Which portion of the film was exposed most?

A6 - The part next to the green portion of the leaf.

Q7 - What is the color of this portion of the leaf?

A7 - Green

Q8 - If that portion of the leaf were tested for sugar, would you expect a positive reaction?

A8 - Yes

Q9 - Which substance produced contains the carbon-14?

A9 - The sugar.

## EXPERIMENT 8-6: PHOSPHOROUS UPTAKE IN THE GREEN PLANT

The purpose of this experiment is to: (1) see if phosphorous is taken up by a green plant, (2) if taken up, see where it is used, and (3) determine if a plant deficient in phosphorous will take it up more rapidly.

OBEJCTIVES:

Given $^{32}P$, autoradiograph supplies and tomato plants, the student shall determine that phosphorous is taken up by plants, and that a phosphorous deficient plant will take it up more rapidly.

MATERIALS:

Phosphorous-32
Autoradiograph supplies
2 tomato plants
Plastic gloves
Safety tray
Ringstand
2 buret clamps
4 test tubes, 10 mm x 100mm
Eye dropper
Nutrient solution A (with phosphorous)
Nutrient solution B (without phosphorous)
Cotton
Light source - suitable for plant growth
Razor blade

ADVANCE PREPARATION:

Prepare nutrient solutions (see special materials). Order phosphorous-32 in advance.

HINTS:

To obtain a decided difference in the regular and phosphorous deficient plant, they might need to be left in the solutions for more than 24 hours.

TYPICAL RESULTS:

Q1 - Is phosphorous necessary for a healthy plant?

A1 - Yes, the deficient plant is not as dark a green.

Q2 - How do the plants compare?

A2 - About the same.

Q3 - Did either or both of the plants take up the phosphorous-32?

A3 - Yes, both did.

Q4 - Does the distribution of phosphorous seem to be even or localized?

A4 - Some all over but a greater concentration in stems and veins.

Q5 - If it is concentrated, where does it seem to be the most heavily concentrated?

A5 - In the stems and veins.

Q6 - Which plant took up the most radioactive phosphorous?

A6 - The phosphorous deficient plant.

Q7 - What determines the amount of an element a plant will take up?

A7 - The plant's need for the element.

## EXPERIMENT 8-7: PHOSPHOROUS AND PHOTOSYNTHESIS

The purpose of this experiment is to show that more phosphorous is used in photosynthetic activity than in areas of less, and that young leaves take up more phosphorous than older leaves.

### MATERIALS:

Phosphorous-32
Autoradiograph supplies
Coleus plant
250 ml erlenmeyer flask
400 ml beaker
1 ml pipette and propipetter
Light source
Cotton
Razor blade
Aluminum foil
Plastic wrap
Safety tray & liner
Plastic gloves

### ADVANCE PREPARATION:

Order the phosphorous-32 in advance.

### HINTS:

If a young coleus plant is used, wash soil from roots and use entire plant. Doubling the amount of P-32 may be necessary to obtain a good autoradiograph.

TYPICAL RESULTS:

Q1 - Which leaves show the highest concentration of phosphorous?

A1 - The ones in the light.

Q2 - Compare the phosphorous concentration of the leaves in the dark with those in the light.

A2 - Both leaves in the light showed exposure, in addition the young leaf in the dark showed a little exposure.

Q3 - Is phosphorous uptake related to photosynthesis?

A3 - Yes.

Q4 - Compare the phosphorous concentration in the old and young leaves. If there is a difference, suggest a possible reason.

A4 - The young leaf in the dark contained a greater phosphorous concentration than the old leaf in the dark. The young leaf apparently uses phosphorous to grow.

## EXPERIMENT 8-8: COLORED LIGHT AND PHOTOSYNTHESIS

The purpose of this experiment is to investigate the effect of various light colors on photosynthesis.

### OBJECTIVES:

Given $^{14}C$, aquatic plants, and different colored cellophane, the student shall discover that different colored lights effect the rate of photosynthesis and that the best colored light for photosynthetic rate is red.

### MATERIALS:

Carbon-14 ($Na_2{}^{14}CO_3$)
Colored cellophone: red, green, and blue
Light source
Boiled tap water or distilled water
Safety tray & liner
Plastic gloves
5 test tubes (25 x 200 mm) with stoppers to fit
Forceps

250 ml beaker
400 ml beaker
Aluminum foil
G-M tube and scaler

ADVANCE PREPARATION:

Obtain C-14 in advance.

HINTS:

Check the activity per unit volume of C-14 solution to determine what volume is needed to obtain 20 $\mu$c.

TYPICAL RESULTS:

| COLOR | CORRECTED COUNTS/MINUTE |
|---|---|
| White | 2757 |
| No light | 42 |
| Red | 1779 |
| Green | 464 |
| Blue | 481 |

Q1 - For which color was there the greatest $^{14}CO_2$ absorption?

A1 - Red.

Q2 - For which was there the least?

A2 - Green and blue.

Q3 - How did the $^{14}CO_2$ absorption of the plant in the white light compare with those in colored light?

A3 - Greater.

Q4 - How did the $^{14}CO_2$ absorption of the plant that received no light (aluminum foil) compare with the others?

A4 - Much less

Q5 - Do different colored lights (different wave lengths) affect the efficiency of photosynthesis?

A5 - Yes.

## EXPERIMENT 8-9: THE EFFECT OF LOW DOSE RADIATION ON PLANT GROWTH

The purpose of this experiment is to show that low dose radiation exposure will stimulate plant growth.

### OBJECTIVES:

Given radish seeds and a Gammator, the student shall learn that low doses of radiation stimulate plant growth.

### MATERIALS:

Small vial or other container to hold seeds while being irradiated
Filter paper (3 thicknesses)
10 Petri dishes (11 cm in diameter)
Radish seeds
Label tape
Gammator

### ADVANCE PREPARATION:

None.

### HINTS:

None.

### TYPICAL RESULTS:

| | GROWTH | % GERMINATION |
|---|---|---|
| Control | 9.1 cm | 90 |
| Irradiated (2 min) | 9.5 cm | 86 |

Q1 - How did 2 minutes of irradiation affect plant growth?

A1 - A little more growth.

Q2 - How did 2 minutes of irradiation affect seed germination?

A2 - A little less germination.

Q3 - How could low dose radiation help the farmer in the production of certain foods?

A3 - May stimulate growth.

## CHAPTER 9

### EXPERIMENT 9-1: BRAIN SCAN

The purpose of this experiment is to "model" a brain scanning technique for locating a tumor.

OBJECTIVES:

Given a head figure and G-M tube, the student shall locate a radioactive source on the head tube, and compare this technique with using tracers to locate possible tumors in a medical patient.

MATERIALS:

G-M tube
Scaler or count rate meter
Figure of head to be surveyed
Timer

ADVANCE PREPARATION:

Prepare figure of head to be surveyed. (See special materials section.)

HINTS:

None

TYPICAL RESULTS:

Q1 - In what area of the head is the tumor apparently located? (Use grid coordinates of the mask to describe your answer.)

A1 - Centered around E10.

Q2 - The brain scan you just completed was that of a side view. What other views, if any, would you want to take to more precisely locate the tumor?

A2 - Front and top.

Q3 - The method you just used was rather time consuming. Suggest a system which would speed up the scanning process.

A3 - Devise a system which moves and records automatically.

Q4 - What are the advantages of using the scanning method?

A5 - Painless, quick and accurate.

## EXPERIMENT 9-2: RENAL OR KIDNEY SCANNING

The purpose of this experiment is to "model" a system for diagnosing kidney disorders.

### OBJECTIVES:

Given a kidney model and G-M tube, the student shall determine, by tracer technique, the difference between a "normal" kidney and an abnormal kidney, and observe the difference between a "hot spot" and a "cold spot".

### MATERIALS:

Kidney models with grid layout

G-M tube and scaler

Graph paper for drawing kidney activity

### ADVANCE PREPARATION:

Prepare kidney model. (See special materials section.)

### HINTS:

Don't reveal in advance the difference between "hot" spots and "cold" spots.

### TYPICAL RESULTS:

Q1 - How do the two scans compare?

A1 - The scan of the abnormal kidney revealed a section of no activity, indicating a non-functioning portion of the kidney.

Q2 - In the kidney scan, how do abnormalities appear?

A2 - As blank or "cold" spots in the scan.

## EXPERIMENT 9-3: CHEMICAL UPTAKE IN FROGS

The purpose of this experiment is to observe the difference in phosphorous uptake by various tissues in a frog.

### OBJECTIVES:

Given $^{32}P$, frog, and G-M tube, the student shall discover which organ has the greatest uptake of $^{32}P$.

## MATERIALS:

- Frog
- Phosphorous-32 solution
- Cotton cloth
- Chloroform
- Planchets
- Dissecting materials
- 2 ml syringe and needle
- Safety tray and liner
- Plastic gloves
- G-M tube and scaler

## ADVANCE PREPARATION:

Order phosphorous-32 in advance.

## HINTS:

None.

## TYPICAL RESULTS:

| ORGAN | WEIGHT OF ORGAN (g) | ACTIVITY c/m | CORRECTED ACTIVITY c/m | UPTAKE c/m/mg |
|---|---|---|---|---|
| Liver | 1.2 | 265 | 241 | 0.2 |
| Heart | 0.6 | 72 | 48 | 0.08 |
| Lung | 1.0 | 65 | 41 | 0.04 |
| Stomach & Intestines | 2.1 | 173 | 149 | .071 |
| Bone | 1.0 | 240 | 216 | .216 |
| Fat | 0.7 | 44 | 20 | .028 |
| Skin | 0.3 | 171 | 154 | .51 |
| Muscle | 0.6 | 62 | 38 | .063 |

FIGURE 9-4

Q1 - Which organ had the greatest uptake of phosphorous-32?

A1 - Skin, bone and liver.

Q2 - Which organ had the least uptake?

A2 - Fat

Q3 - How could a procedure of this type be used in the study of body functions?

A3 - Many answers, such as tracing, comparing abnormal organs with normal organs, etc.

## EXPERIMENT 9-4: BLOOD VOLUME

The purpose of this experiment is to "model" a procedure for determining blood volume using a radioisotope.

### OBJECTIVES:

Given a model animal, G-M tube and radioisotope, the student shall calculate the volume of "blood" in the animal. Given the same model, lacking an unknown quantity of "blood", the student shall calculate the volume of "transfusion" necessary to return the blood volume to normal.

### MATERIALS:

Model (hollow rubber animal)
Minigenerator (Sn 113/In $113^m$)
G-M tube and scaler
Ringstand and buret clamp
3 15 ml beakers
Hypodermic syringe
Plastic gloves
Safety tray and liner

### ADVANCE PREPARATION:

None.

### HINTS:

The hollow rubber animal is a squeeze toy with the noisemaker replaced with a 1-hole rubber stopper. For most accuracy the internal volume of the animal should be less than 50 ml.

### TYPICAL RESULTS:

| | | |
|---|---|---|
| Activity of 1.0 ml injected control | 865 | c/m |
| Activity of 1.0 blood removed | 46 | c/m |
| Volume of injected control | | 1.0 ml |
| Volume of blood removed | | 1.0 ml |
| Total "blood" volume | 19 | ml |

Q1 - What is your calculated value for the "blood" volume of the model?

A1 - 19 ml.

Q2 - Does the half-life of the radioactive solution affect the results of this experiment? Explain

A2 - No, because the injected and removed samples decayed together and were counted together.

Q3 - What difficulties could arise if a radioisotope such as phosphorous-32 were used in an actual patient?

A3 - It could be rather quickly absorbed by certain tissues.

Q4 - Does the volume injected have to be the same as the volume of blood removed?

A4 - Yes.

Q5 - How does the volume measured with the graduated cylinder compare with your answer to Q1?

A5 - Very close.

Q6 - What volume did you find necessary?

A6 - 5 ml.

## EXPERIMENT 9-5: A MODEL FOR THERAPEUDIC UPTAKE

The purpose of this experiment is to "model" the absorption of specific elements by certain organs.

### OBJECTIVES:

Given a G-M tube, radioisotope and sodium hydroxide, the student will demonstrate the manner by which a radioisotope is used to treat tumors.

### MATERIALS:

G-M tube
Ringstand and mall rings to hold funnels
Scaler
Minigenerator (Sn 113/In $113^m$)
Test tube
4 15 ml beakers
2 funnels
Filter paper

Small amount of sodium hydroxide solid
Safety tray & liner*
Plastic gloves

ADVANCE PREPARATION:

None.

HINTS:

Emphasize that solutions should be poured into the funnels slowly.

TYPICAL RESULTS:

| | A | | B | |
|---|---|---|---|---|
| | Activity (cpm) | Corrected Activity (cpm) | Activity (cpm) | Corrected Activity (cpm) |
| Initial Reading | 755 | 731 | 780 | 756 |
| Filter Paper (Precipitate) | 180 | 156 | 670 | 646 |
| Collecting Beaker (Filtrate) | 523 | 499 | 104 | 80 |

FIGURE 9-8

Q1 - Which filter paper showed the highest count?

A1 - Filter B.

Q2 - If the sodium hydroxide represents a tumor, what type of radiation would be best suited for destroying the tumor? (α, β or γ) (assume the isotope you choose has an affinity for the tumor).

A2 - Alpha.

Q3 - Why would the type of radiation you choose for Q2 be best?

A3 - It is most likely to kill surrounding cells without the damage extending too far.

Q4 - What advantages would this means of treating a diseased organ have over treatment from external means of radiation?

A4 - Since destruction of tissue is localized, other parts of the body aren't affected.

## EXPERIMENT 9-6: OUTSIDE BODY TESTING

The purpose of this experiment is to "model" a procedure for the treatment of blood samples with radioactive chemicals for the purpose of detecting thyroid disorders.

### OBJECTIVES:

Given a G-M tube and "chemical extractions of red blood cells from 4 patients", the student shall identify abnormally functioning thyroid glands.

### MATERIALS:

G-M tube and scaler
Ringstand and buret clamp
Samples to be tested: A, B, C, & D
4 uptake sponges
10 ml graduated cylinder
4 test tubes
Stirring rod
4 planchets
Forceps
Safety tray & liner
Plastic gloves

### ADVANCE PREPARATION:

Prepare samples to be tested and uptake sponges. (See special materials section.)

### HINTS:

None.

### TYPICAL RESULTS:

|  | ACTIVITY BEFORE SOAKING c/m |  | ACTIVITY AFTER SOAKING c/m | % UPTAKE |
|---|---|---|---|---|
| Sponge 1 | 194 | (A) | 176 | 9% |
| Sponge 2 | 142 | (B) | 113 | 20% |
| Sponge 3 | 150 | (C) | 87 | 37% |
| Sponge 4 | 170 | (D) | 84 | 50% |

FIGURE 9-10

Q1 - What is the percent uptake of each of the four samples? List the samples in descending order according to their percent uptake.

A1 - D - 50%, C- 37%, B - 20%, A - 9%.

Q2 - Which patients would you suspect of having abnormally functioning thyroid glands?

A2 - A and D.

SAMPLE TESTS (MAY BE COPIED)

## INTRODUCTION TO NUCLEONICS

### CHAPTER 1 AND 2

DIRECTIONS: Select the best answer to each question and place its letter on the answer sheet. Do not write on the test.

1. Diagram A shows the initial reading of a dosimeter. Diagram B shows the same dosimeter after a student has worn it for a period of time. What radiation dose did the student receive during this time?

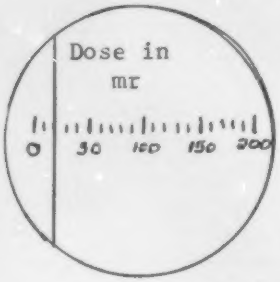


Diagram A

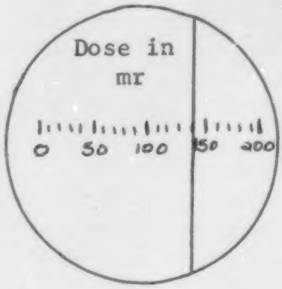


Diagram B

A. 20 mr
B. 80 mr
C. 100 mr
D. 120 mr
E. 140 mr

2. A sheet of unexposed X-ray film is wrapped in heavy light-tight paper. Separate sources of alpha, beta, and gamma radiation are placed on the paper and left overnight. Which source(s) would you expect to expose the film?

A. Alpha only
B. Beta only
C. Gamma only
D. Beta and gamma
E. Alpha, beta, and gamma

3. The experiment described in Question 2 is repeated with the following change: In a darkroom, the same three radioactive sources are placed inside the heavy paper which wraps the X-ray film. Which would you now expect to expose the film?

A. Alpha only
B Beta only
C. Gamma only
D. Beta and gamma
E. Alpha, beta, and gamma

4. A radioactive source is placed in a cloud chamber. After a few minutes, heavy straight-line tracks appear to be coming from the source. Which type of radiation must be present?

   A. Alpha
   B. Beta
   C. Gamma
   D. Beta and gamma
   E. Alpha, beta, and gamma

5. A charged rod repels a charged pith ball. The rod and the pith ball have:

   A. The same charge
   B. Opposite charges
   C. Impossible to tell from the given data

6. When a charged rod is brought near the knob of a charged electroscope, the leaves collapse (move together). The charged rod and the charged electroscope must have had:

   A. The same charge
   B. Opposite charge
   C. Impossible to tell from the given data

7. Sample 1 (a radioactive material) causes a charged electroscope to discharge in one hour. Sample 2, containing a different amount of the same radioactive material, causes an identical electroscope to discharge the same amount in two hours. Which sample, if any, would produce the largest dosimeter reading in 24 hours?

   A. Sample 1
   B. Sample 2
   C. Both the same

8. Because the dosimeters are enclosed in a fairly heavy metal case, they are only useful in detecting what type of radiation?

   A. Alpha
   B. Beta
   C. Gamma
   D. All types

9. In one hour a radioactive source produces about $6.24 \times 10^9$ ion pairs per cubic centimeter of dry air at standard temperature and pressure. A dosimeter, charged to zero, is placed at this location for one hour. After that time the dosimeter should read:

A. .5 r
B. 1.0 r
C. 2.0 r
D. 3.0 r
E. 5.0 r

10. A dose of 350 mr is equal to a dose of:

A. .350 r
B. 35.0 r
C. 3500 r
D. 35,000 r
E. 350,000 r

11. If a dose of 20 mr is received in 10 minutes, the dose rate would be:

A. 20 mr/hr
B. 60 mr/hr
C. 120 mr/hr
D. 200 mr/hr
E. 500 mr/hr

12. A scaler (without a G-M tube) will register counts in response to:

A. Alpha radiation
B. Beta radiation
C. Gamma radiation
D. Electrical pulses
E. Light flashes

The data table shown below is to be used in answering Questions 13 and 14. The main body of the table represents counts per minute corrected for background.

| Shield<br>Source | None | Paper 1 mm Thick | Aluminum 1 mm Thick | Lead 1 mm Thick |
|---|---|---|---|---|
| #1 | 1080 c/m | 1070 c/m | 1010 c/m | 650 c/m |
| #2 | 1060 c/m | 0 c/m | 0 c/m | 0 c/m |
| #3 | 1100 c/m | 1020 c/m | 350 c/m | 0 c/m |

If one source was primarily alpha radiation, one beta radiation, and one gamma radiation:

13. Which was the alpha source?

A. #1
B. #2
C. #3

14. Which was the beta source?

A. #1
B. #2
C. #3

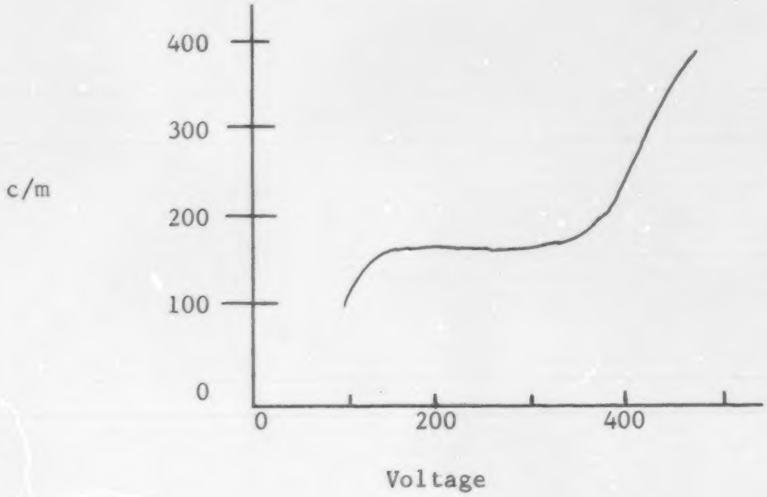
15. A student determines the background count to be 20 counts per minute. He then checks a sample and finds that the scaler reads 360 after a 3-minute count. What is the activity of the sample in counts per minute after it is corrected for background radiation?

A. 60 counts/minute
B. 100 counts/minute
C. 113 counts/minute
D. 340 counts/minute
E. 380 counts/minute

16. If a G-M tube will respond to alpha radiation, its window must be:

A. at least as thin as the lead shields you used.
B. at least as thin as the aluminum shields you used.
C. at least as thin as the cardboard shields you used.
D. thinner than any of the above.

17. This is a graph of counts per minute vs. voltage for a G-M tube:



What is the proper operating voltage?

A. 100 volts
B. 150 volts
C. 250 volts
D. 400 volts
E. 450 volts

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18. Based on Experiment 12, which radiation, if any, consists of charged particles?

- A. Beta
- B. Gamma
- C. Beta and gamma
- D. Neither beta or gamma

19. Which of the following would be the best conductor of electricity?

- A. Sugar solution
- B. Salt solution
- C. Alcohol solution
- D. Distilled water

20. Irradiating a solution causes its conductivity to:

- A. Increase
- B. Decrease
- C. Stay the same

## INTRODUCTION TO NUCLEONICS

## CHAPTER 3

DIRECTIONS: For each question, place the letter which corresponds to the best answer on the answer sheet. Do not write on this test.

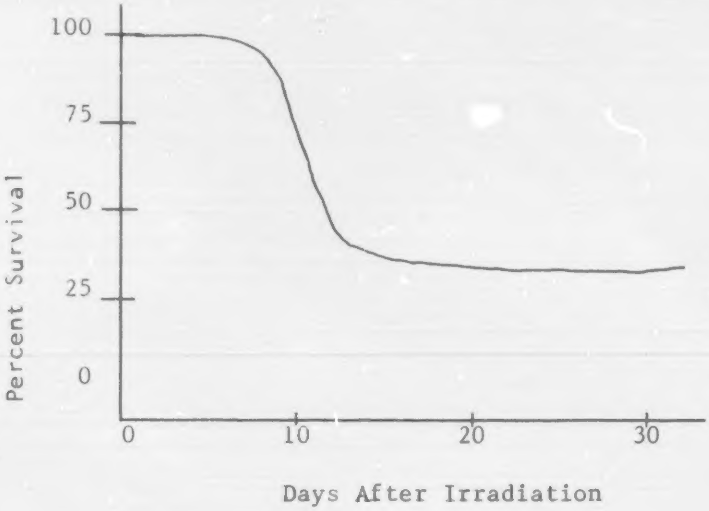
1. Food sample A has been irradiated for 24 hours in a Gammator. Food sample B has been contaminated with a radioactive material. Which sample(s) might be harmful if eaten:

   A. Only A
   B Only B
   C. Both A and B
   D Neither A nor B

2. To avoid the most possible natural radiation, a person should:

   A. Take an airplane to an altitude of 3 miles.
   B. Live in Denver, Colorado (altitude 1 mile).
   C. Go 1 mile down a mine shaft.
   D. Surround yourself with lead bricks
   E. Go into a natural stone building.

3-4. Refer to the following graph to answer Questions 3 and 4:



3. Some flour beetles were irradiated in a Gammator. Approximately when did the beetles begin to die?

   A Immediately after irradiation
   B. 10 days after irradiation
   C. 20 days after irradiation
   D. 30 days after irradiation

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4. What percent of the beetles were not killed by the radiation?

A. 0%
B. 30%
C. 45%
D. 65%
E 100%

5-6 The following data table is to be used in answering Questions 5 and 6. Samples of seed X and Seed Y were irradiated for various times with the following results:

| Dose (kr) | Seed | Number Planted | Number Germinated | Average Height (mm) |
|---|---|---|---|---|
| 0 | x | 100 | 95 | 83 |
| 2.5 | x | 100 | 94 | 71 |
| 10 | x | 100 | 85 | 70 |
| 40 | x | 100 | 50 | 37 |
| 160 | x | 100 | 0 | - |
| 0 | Y | 100 | 93 | 22 |
| 2.5 | Y | 100 | 92 | 24 |
| 10 | Y | 100 | 90 | 24 |
| 40 | Y | 100 | 85 | 23 |
| 160 | Y | 100 | 80 | 19 |

5. What radiation dose produced the same effect on the germination of seeds Y that a 10 kr dose produced on Seeds X?

A. 0 kr
B. 2.5 kr
C. 10 kr
D. 40 kr
E. 160 kr

6. Samples of Seeds X and Y are given radiation doses of 40 kr and then planted. Which seeds would you expect to produce plants of normal size?

A. Only X
B. Only Y
C Both X and Y
D. Neither X nor Y

7-11. The following paragraphs should be used in answering Questions 7 through 11.

A group of 60 healthy goldfish, of the same age, were separated into two tanks (30 in each) and were given adequate food and oxygen. The fish in Tank A were exposed to a large dose of gamma radiation. The fish in Tank B were not irradiated. Throughout the remainder of the experiment, the fish in both tanks were treated the same.

Within one week, 10 of the fish in Tank A die. The eyes of the surviving fish in Tank A turned cloudy. All the fish in Tank B lived and remained normal. The surviving fish in both tanks continued to live and reproduce. White spots appeared on some of the offspring in Tank A. All the offspring in Tank B were gold in color.

7. Why were the fish separated into two tanks?

   A. It wasn't necessary for the experiment. Since nothing happened to the fish in Tank B, they served no useful purpose.

   B. In case all the fish in Tank A die, we could use the fish in Tank B to repeat the experiment.

   C. Without Tank B we would have no evidence that the changes in the fish in Tank A were due to radiation.

8. Which of the following changes was a somatic effect?

   A. Clouding of the eyes
   B. White spots on offspring
   C. Normal colored, clear eyed offspring

9. Which of the following was a genetic effect?

   A. Clouding of the eyes
   B. White spots on offspring
   C. Death of fish in Tank A

10. Which best describes the radiation dose given to the fish in Tank A?

   A. LD-67 - 7 days
   B. LD-50 - 7 days
   C. LD-33 - 7 days
   D. LD-17 - 7 days
   E. LD-10 - 7 days

11. Which one of the following statements is most likely true?

A. The offspring of the fish in Tank A would have cloudy eyes.
B. The offspring of the fish in Tank B would have cloudy eyes.
C. The offspring of the fish in both tanks would have cloudy eyes.
D. The offspring of the fish in both tanks would have clear eyes.

12. A bottle contains a liquid radioisotope which produces gamma radiation. To determine if some of the radioisotope has run down the outside of the bottle you could:

A Monitor the bottle with a survey meter.
B Wipe the bottle with a tissue and monitor the tissue.
C Place a photographic film around the bottle and develop.
D Assume that it is contaminated and throw the bottle away.

13. Radioactive samples W, X, Y, and Z all produce the same count when placed 5 cm from a G-M tube connected to a scaler

W is a solid in an open vial.
X is a solid sealed in a vial.
Y is a liquid in an open vial.
Z is a liquid sealed in a vial.

Which sample is potentially most hazardous to work with?

A. Sample W
B. Sample X
C Sample Y
D Sample Z

14. Which surface would be easiest to decontaminate?

A Glass
B. Wood
C. Brick
D. Cloth
E. Stone

15. Which would be most hazardous assuming all sources are of the same strength and produce the same type of radiation?

A 1 minute external exposure to the source each day for a week.
B A single dose of a tissue seeker taken by mouth.
C. A single dose of a non-tissue seeker taken by mouth.

16. Some soil is contaminated with radioactive iron  Spinach, a plant rich in iron, is grown in this soil. What precautions should you take before eating the spinach?

A. No precautions are necessary since only the soil was contaminated.
B Wash the leaves thoroughly in running water.
C. Cook thoroughly to sterilize.
D It is likely that none of the above precautions will protect you.

17. Which type of external radiation produces the greatest hazard to internal organs?

A. Alpha
B Beta
C Gamma

18. Which type of radiation presents no hazard externally but is perhaps the most hazardous if the source enters the body?

A. Alpha
B. Beta
C. Gamma

19. Which type of radiation produces the greatest concentration of ion pairs?

A Alpha
B. Beta
C. Gamma

20. A person can receive a 25 r whole body dose of penetrating radiation without any obvious injury or ill effects. Which of the following statements is true?

A A 25 r dose of penetrating radiation presents no hazard.

B. A person could safely receive any amount of radiation so long as it was given in separate 25 r doses.

C. A dose of 25 r may produce genetic damage which could appear in later generations.

D. A dose of 50 r to the hands is probably more dangerous than the dose of 25 r to the entire body.

# INTRODUCTION TO NUCLEONICS

## CHAPTER 4

DIRECTIONS: Select the best answer for each question and place its corresponding letter on the answer sheet. Do not write on this test

Refer to the following data table to answer questions 1, 2, and 3

ACTIVITY OF A SOURCE AT VARIOUS TIMES

| Time | 0 hr. | 1 hr. | 2 hr. | 3 hr. |
|---|---|---|---|---|
| Activity | 400 c/m | 200 c/m | (X) | (Y) |

1. What activity would you expect after 2 hrs. (reading X)? About:

   A. 200 c/m
   B. 100 c/m
   C. 50 c/m
   D. 25 c/m
   E. 0 c/m

2. What activity would you expect after 3 hours (reading Y)? About:

   A. 200 c/m
   B. 100 c/m
   C. 50 c/m
   D. 25 c/m
   E. 0 c/m

3. What is the half-life of the sample used in the above example?

   A. ½ hour
   B. 1 hour
   C. 2 hours
   D. 3 hours
   E. 6 hours

4 Refer to Appendix D to answer the following question:

The activity of a radioactive sample is measured every 24 hours for 7 days.

The results were as follows:

| Day | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Activity c/m | 1000 | 760 | 590 | 460 | 360 | 280 | 220 | 170 |

The sample might be composed of:

A. Cerium-144
B. Indium-113
C. Phosphorous-32
D. Praseodymium-144
E. Yttrium-90

5. Two sources of gamma radiation were found to produce the same initial radiation count. Sample A has a half-life of 1 hour. Sample B has a half-life of 3 weeks. Which sample would produce the greatest disposal problem?

   A. Sample A
   B. Sample B
   C. Both the same
   D. Impossible to tell from the information given

6. 2 meters from a radioactive source, the radiation count is 1800 c/m. What count would you expect 6 meters from the same source?

   A. 200 c/m
   B. 300 c/m
   C. 900 c/m
   D. 1800 c/m
   E. 5400 c/m

7. Which of the following would produce the greatest radiation dose? (Assume that the source has a long half-life.)

   A. A 1-minute exposure at a distance of 1 meter.
   B. A 2-minute exposure at a distance of 2 meters.
   C. Both doses would be the same.

The following data table should be used to answer questions 8, 9, and 10. The main body of the table represents the counts per minute from three sources (X, Y, and Z) when shielded with various materials.

| Shield / Source | No Shield | Cardboard (1 sheet) | Aluminum (1 sheet) | Lead (1 sheet) | Lead (2 sheets) |
|---|---|---|---|---|---|
| X | 500 c/m | 500 c/m | 480 c/m | 250 c/m | 125 c/m |
| Y | 500 c/m | 0 c/m | 0 c/m | 0 c/m | 0 c/m |
| Z | 500 c/m | 400 c/m | 20 c/m | 0 c/m | 0 c/m |

8. Which source was probably a gamma source?

   A. Source X
   B Source Y
   C. Source Z

9. Which source was probably an alpha source?

   A. Source X
   B. Source Y
   C. Source Z

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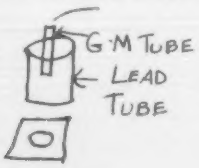
10. Which of the following represents one half-thickness for the above gamma source?

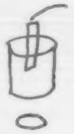
A. 1 sheet of cardboard (as listed in data table)
B. 1 sheet of aluminum (as listed in data table)
C. 1 sheet of lead (as listed in data table)
D. 2 sheets of lead (as listed in data table)

11. Which of the following arrangements would you expect to produce the highest radiation count? The same G-M tube and beta source are used in each case and the distance from the source to the G-M tube is the same in each case.

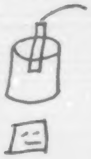


Source on lead sheet

(a)

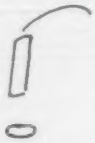


(b)

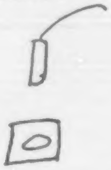


Source under lead sheet

(c)



(d)



Source on lead sheet

(e)

12. A radioactive sample undergoes $7.4 \times 10^{12}$ d/s. Its activity is:

A. $1 \times 10^{3}$ curies
B. $2 \times 10^{4}$ curies
C. $5 \times 10^{-3}$ curies
D. $2 \times 10^{2}$ curies
E. $5 \times 10^{2}$ curies

13. A 2μc source undergoes how many disintegrations per second?

A. 740 d/s
B. $2 \times 10^{3}$ d/s
C. $7.4 \times 10^{4}$ d/s
D. $2 \times 10^{-6}$ d/s
E. $1.85 \times 10^{16}$ d/s

14. A radioactive sample has an initial activity of 400μc. If its half-life is 3 days, what is its activity after 12 days?

A. 25μc
B. 50μc
C. 133μc
D. 200μc
E. 1200μc

15. A sphere, with a gamma source at its center, has a surface area of 50 square inches. An end window Geiger tube with a window area of 1 square inch is held on the surface of the sphere. Assume the G-M tube detects every particle which reaches it. If the tube detects 100 c/m, the source must be undergoing about:

A. 2 d/m
B. 100 d/m
C 400 d/m
D. 5000 d/m
E. 20000 d/m

16. The radiation unit which takes into account biological damage is the:

A. Roentgen
B. Curie
C. Rad
D. Rem

17. A person is exposed to 10 roentgens of gamma radiation. His dose in rems is about:

A. 1 rem
B. 10 rems
C 100 rems
D. 1,000 rems
E. 10,000 rems

18. Which would cause the most tissue damage if taken internally, a 5 rad alpha source or a 5 rad beta source?

A. 5 rad alpha source
B. 5 rad beta source
C. Both the same

19. Which of the following is not important in estimating the probable damage of 100 rad radiation dose:

A. Kind of radiation
B. Part of body exposed
C. Amount of body exposed
D. Length of time during which exposure occurred
E. None of the above - they are all important

20. What is the maximum permissible accumulated dose (whole body penetrating radiation) for a radiation worker 23 years of age?

A. 25 rems
B. 50 rems
C 60 rems
D. 200 rems
E. 375 rems

# INTRODUCTION TO NUCLEONICS

## CHAPTERS 1-5

DIRECTIONS: Select the best answer to each question and place its corresponding letter on the answer sheet.

1. A charged rod is brought near the knob of a charged electroscope. If the leaves move further apart, the electroscope and the rod had:

   A. The same charge
   B. Opposite charge
   C. Impossible to tell from the given data

2. A dosimeter is a miniature:

   A. Geiger counter
   B. Cloud chamber
   C. Electroscope
   D. Gammator
   E. Scaler

3. A dose of 35 r is equal to a dose of:

   A. .035 mr
   B. 3.5 mr
   C. 3500 mr
   D. 35,000 mr
   E. 350,000 mr

4. A scaler (without a G-M tube) will register counts in response to:

   A. Alpha radiation
   B. Beta radiation
   C. Gamma radiation
   D. Electrical pulses
   E. Light flashes

5. A student determines the background count to be 40 counts per minute. He then checks a sample and finds that the scaler reads 720 after a 3-minute count. What is the activity of the sample in counts per minute after it is corrected for background radiation?

   A. 120 c/m
   B. 200 c/m
   C. 226 c/m
   D. 680 c/m
   E. 720 c/m

6. Irradiating a solution causes its conductivity to:

   A. Increase
   B. Decrease
   C. Stay the same

7. Which would best detect alpha radiation?

   A. Film wrapped in heavy paper
   B. G-M tube with an aluminum "window" 1 mm thick
   C. The type of dosimeters you used in class
   D. A cloud chamber with the source inside

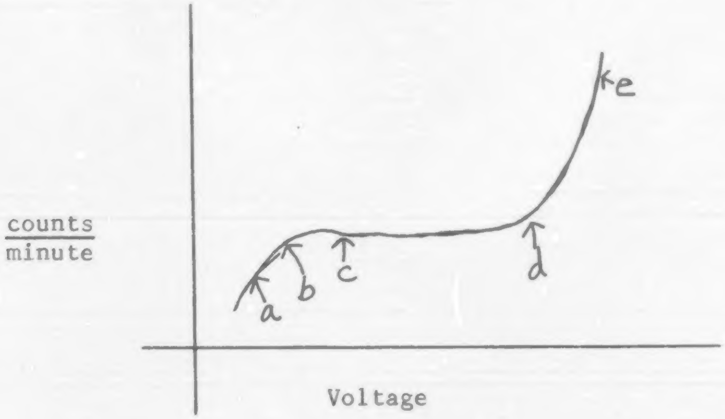
8. Which of the following has no electric charge?

   A. Alpha particle
   B. Beta particle
   C. Proton
   D. Electron
   E. Neutron

9. The process of radioactive particles knocking electrons from atoms to form charged particles is called:

   A. Generation
   B. Electrozation
   C. Radiation
   D. Ionization
   E. Fluctuation

10. Which of the following shows the correct operating voltage for a G-M tube?



11. Irradiated food:

   A. Is safe to eat
   B. Is more dangerous than contaminated food
   C. Is radioactive
   D. Is safe only after it is decontaminated

12 Which place is free of background radiation?

A An extremely high altitude
B Deep in a cave
C In a brick building
D In bright sunlight
E None of the above

13 Damage to living organisms from exposure to radiation:

A Is greatest if the dose is spread over a long period of time.
B Occurs only if the radiation source is inside the body.
C May not be evident until quite some time after the exposure.
D Does not depend on the type of radiation.
E Affects only the extremities (arms & legs).

14 Irradiation of living seeds might affect what combination of the following:

I. The ability of the seeds to germinate
II. The growth of the plant after germination
III Plants in later generations

A I only
B II only
C I and II only
D. I and III only
E I, II, and III

Use one of the following responses to answer each question 15 through 18.

A Somatic effect
B. Genetic effect

15 Death of an organism from radiation exposure is a:

16 Change in fur color of an irradiated animal is a:

17 Different eye color in the offspring of an irradiated animal is a:

18 Although the probability of occurrence is extremely low, a single radiation particle or ray, in the right spot, can produce a:

19 Which of the following would produce the greatest contamination problem:

A A radioisotope with a short half-life spilled on a smooth surface.
B A radioisotope with a long half-life spilled on a smooth surface
C A radioisotope with a short half-life spilled on a porous surface.
D. A radioisotope with a long half-life spilled on a porous surface.

20. Which of the following would probably present the greatest hazard if taken internally:

- A. A 50 μc alpha source which is a tissue seeker.
- B. A 50 μc gamma source which is a tissue seeker.
- C. A 50 μc alpha source which is not a tissue seeker.
- D. A 50 μc gamma source which is not a tissue seeker.

21. Which of the following will not decrease the radiation dose a person receives?

- A. Decreasing the time of exposure
- B. Increasing the distance from the source
- C. Shielding the source
- D. Using a source whose activity and type of radiation is the same but which has a very long half-life

22. Following is the data for the activity of a radioactive sample:

(NOTE: All counts are corrected for background radiation.)

| Time (hr.) | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
|---|---|---|---|---|---|---|---|---|
| Activity (c/m) | 200 | 165 | 140 | 118 | 102 | 87 | 74 | 62 |

What is the half-life of the sample?

- A. 2.5 hr.
- B. 7.3 hr.
- C. 8.1 hr.
- D. 10.8 hr.
- E. 12.6 hr.

23. A radioisotope has a half-life of 2.5 hr. If its initial activity was 2000 c/m, what would you predict for its activity after 10 hours?

- A. 125 c/m
- B. 200 c/m
- C. 250 c/m
- D. 400 c/m
- E. 800 c/m

24. When a G-M tube is placed 1 foot from a radioactive source, it causes the scaler to register 1600 counts in 1 minute. What would you predict for a 1-minute count if the G-M tube were placed 4 feet from the same source?

- A. 25 c/m
- B. 100 c/m
- C. 400 c/m
- D. 800 c/m
- E. 6400 c/m

Answer each question (25-28) with one of the following responses:

A Roentgen
B. Curie
C Rad
D Rem
E RBE

25 A unit which measures the activity of a source of radiation:

26. A unit of dose which takes into account the biological damage caused by radiation:

27 For most beta and gamma radiation, its value is equal to 1:

28 A unit of exposure to gamma or X-rays:

29 How much skin radiation dose can a radiation worker receive in 1½ years?

A. 10 rems
B. 15 rems
C 16 rems
D 20 rems
E 60 rems

The following information is used to answer questions 30-33.

Atom X has 15 protons and 17 neutrons.

30 What is the atomic number of X?

A 2
B 15
C 17
D 30
E 32

31. What is the atomic weight of Atom X? (Refer to question 30.)

A 2
B. 15
C. 17
D 30
E 32

32. Another atom has 15 protons and 15 neutrons

A It is a different element than X
B It is another isotope of element X.
C Its atomic number is 30

33 Element X is:

A. Phosphorous
B Zinc
C. Germanium
D Oxygen
E Boron

34. If a radioactive element is combined with a non-radioactive element to form a chemical compound:

- A. It loses its radioactivity.
- B. Its radioactivity increases.
- C. Radioactive elements do not form compounds.
- D. It reacts like a non-radioactive isotope of the same element but remains radioactive.
- E. It will react only with other radioactive elements.

35. ${}^{92}_{234}\text{U} \longrightarrow \alpha + \underline{\hspace{4cm}}$

- A. ${}^{93}_{234}\text{Np}$
- B. ${}^{92}_{230}\text{Th}$
- C. ${}^{92}_{230}\text{U}$
- D. ${}^{91}_{234}\text{Pa}$
- E. ${}^{88}_{232}\text{Ra}$

36. Atoms of one element can be converted to atoms of other elements by all of the following processes except:

- A. Radioactive decay
- B. Fission
- C. Fusion
- D. Chemical reaction

37. Which of the following cannot be detected directly, using a thin window Geiger tube and a scaler:

- A. Alpha particles
- B. Beta particles
- C. Gamma rays
- D. Neutrons

38. Which of the following make good "bullets" for a fission reaction?

- A. Alpha particles
- B. Neutrons
- C. Beta particles
- D. Protons
- E. Gamma rays

39. If a nuclear reactor becomes super-critical and the reaction is not controlled, it will:

A. Explode
B. Melt down
C. Start a fusion reaction
D. Lose all its radioactivity

40. Atomic reactors can be used for all the following except:

A. To produce new elements through transmutation
B. To provide electrical power
C. To produce radioisotopes
D. To destroy radioactive wastes

The following choices are to be used to complete each of the remaining questions (41-60).

A. Alpha only
B. Beta only
C. Gamma only
D. Alpha and beta only
E. Beta and gamma only

41. Which radiation is most penetrating?

42. Which radiation is least penetrating?

43. Which radiation has the largest electrical charge?

44. Which radiation has no electrical charge?

45. Which radiation consists of particles?

46. Which radiation will expose a film wrapped in heavy black paper?

47. Which radiation produces the heaviest tracks in a cloud chamber?

48. Which radiation can be deflected with a magnetic field?

49. Which external radiation is most damaging to the body?

50. Which internal radiation is most damaging to the body?

51. Which external radiation can penetrate the skin but cannot reach the internal organs?

52. Which radiation produces the greatest ion concentration per centimeter of travel?

53. Which radiation is very similar to X-rays?

54. Which radiation is identical to an electron?

55. Which radiation consists of 2 protons and 2 neutrons?

56. Which radiation would be repelled by a negative electrical charge?

57. Which radiation will penetrate a sheet of paper?

58. Which radiation consists of particles with the greatest mass?

59. ${}^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} +$ ____________________

What kind of radiation fills the blank?

60. ${}^{210}_{81}\mathrm{Tl} \longrightarrow {}^{210}_{82}\mathrm{Pb} +$ ____________________

What kind of radiation fills the blank?

## TEST ANSWER - KEY

| CHAPTERS: | | 3 | 4 | 1-5 | | |
|---|---|---|---|---|---|---|
| NUMBERS | 1 D | 1 B | 1. B | 1. A | 26. D | 51 B |
| | 2. D | 2. D | 2. C | 2. C | 27. E | 52. A |
| | 3. E | 3. B | 3. B | 3. D | 28. A | 53. C |
| | 4. A | 4. C | 4. E | 4. D | 29. C | 54. B |
| | 5. A | 5. D | 5 B | 5. B | 30. B | 55 A |
| | 6. B | 6. B | 6. A | 6. A | 31. E | 56 B |
| | 7 A | 7. C | 7. A | 7. D | 32. B | 57. E |
| | 8 C | 8. A | 8. A | 8. E | 33 A | 58. A |
| | 9 D | 9 B | 9. B | 9. D | 34. D | 59. A |
| | 10. A | 10. C | 10. C | 10. C | 35. B | 60. B |
| | 11. C | 11. D | 11. A | 11. A | 36. D | |
| | 12. D | 12. B | 12. D | 12. E | 37. D | |
| | 13. B | 13. C | 13. C | 13. C | 38. B | |
| | 14. C | 14. A | 14. A | 14. E | 39. B | |
| | 15 B | 15. B | 15. D | 15. A | 40. D | |
| | 16. D | 16. D | 16. D | 16. A | 41. C | |
| | 17. B | 17. C | 17. B | 17. B | 42. A | |
| | 18. A | 18 A | 18 A | 18. B | 43. A | |
| | 19 B | 19. A | 19. E | 19. D | 44. C | |
| | 20. A | 20. C | 20. A | 20. A | 45. D | |
| | | | | 21. D | 46. E | |
| | | | | 22. C | 47. A | |
| | | | | 23. A | 48. D | |
| | | | | 24. B | 49. C | |
| | | | | 25. B | 50. A | |

## SUGGESTED FILMS

| AEC NO. | TITLE | TIME (Min) | CHAPTER |
|---|---|---|---|
| 0250 | OPPORTUNITY UNLIMITED | 28 | 1 (C) |
| 0293 | RADIATION DETECTION BY IONIZATION | 30 | 2 |
| 0182 | INVISIBLE BULLETS | 29 | 3 |
| 0296 | RADIATION BIOLOGY | 13½ | 3 (C) |
| 0156 | HARVEST OF AN ATOMIC AGE | 20 | 3 (C) |
| 0288 | PROPERTIES OF RADIATION | 30 | 4 |
| 0001 | A IS FOR ATOM | 15 | 5 (C) |
| 0437 | ATOMS IN AGRICULTURE | 27 | 6 (C) |
| 0424 | ATOMIC MEDICINE | 27 | 6 (C) |
| 0430 | THE WEATHER EYE | 14 | 6 (C) |
| 0127 | FARM FRESH TO YOU | 13½ | 6 (C) |
| 0438 | ATOMIC REVOLUTION IN WOOD | 23 | 6 (C) |

These films are available free of charge and may be ordered by writing to:

USAEC - TIC Film Library
P.O. Box 62
Oak Ridge, Tenn. 37830

Other films are also available from this source. A film catalog can be obtained by writing to the above address.

# SUPPLEMENTAL READING LIST

## SUGGESTIONS FOR ADDITIONAL EXPERIMENTS

| TITLE & AUTHOR | SOURCE |
|---|---|
| Radioisotope Experiments for the<br>Chemistry Curriculum, 1960<br>Norman Radin, Editor | Searle Analytic, Inc.<br>2000 Nuclear Drive<br>Des Plaines, Ill. 60018 |
| Radioisotopes and Inquiry, 1968 | Bio-Atomic Research Foundation<br>Published by: Encyclopaedia<br>Brittanica Educational Corp.<br>425 N. Michigan Avenue<br>Chicago, Illinois, 60611 |
| Nuclear Experiments with Gamma<br>Radiation, 1969<br>Ralph Herold, Shirley Randazzo | Isomedix, Inc.<br>25 Eastmans Road, Box 177<br>Parsippiny, New Jersey 07054 |
| Experiments in Nuclear Science, 1964<br>Gradton D. Chase, etal | Burgess Publishing Company<br>426 South 6th Street<br>Minneapolis, Minnesota 55415 |
| Minigenerator:<br>Experiments in Nucleonics, 1968<br>Biology Experiments in Nucleonics, 1968<br>Henry H. Kramer<br>Wayne Gemmill | Union Carbide<br>Sterling Forest Research Center<br>Tuxedo, New York 10987 |

## SUGGESTIONS FOR THE TEACHER:

| | |
|---|---|
| Radiation Monitoring, 1971<br>James E. Wade, etal. | US Atomic Energy Commission<br>Division of Technical Information<br>P.O. Box 62<br>Oak Ridge, Tennessee |

This is an excellent book for the teacher or motivated student. It is programmed for self instruction. Single copies of this publication may be obtained free by requesting EDM-123 from the above address.

| | |
|---|---|
| Sourcebook on Atomic Energy, 1958<br>Samuel Glasstone | Van Nostrand Reinhold Company<br>Division of Litton Educational<br>Publishing, Inc<br>450 West 33rd Street<br>New York, New York 10001 |
| Radiation Biology, 1968<br>Alison P. Casarett | Prentice-Hall, Inc<br>Englewood Cliffs,<br>New Jersey, 07632 |
| Handbook of Radioactive Nuclides, 1969<br>Yen Wang, Editor | The Chemical Rubber Company<br>18901 Cranwood Parkway<br>Cleveland, Ohio 44128 |

# SUPPLEMENTAL READING LIST

SUGGESTIONS FOR THE STUDENTS:

| TITLE & AUTHOR | SOURCE |
|---|---|
| The World of the Atom Series | U.S. Atomic Energy Commission<br>Technical Information Center<br>P.O. Box 62<br>Oak Ridge, Tennessee 37830 |
| Understanding the Atom Series | U.S. Atomic Energy Commission<br>Technical Information Center<br>P.O. Box 62<br>Oak Ridge, Tennessee 37830 |

Librarians and teachers may obtain free a complete set of each of these series. Request should be made on school or library stationary. IT IS RECOMMENDED THAT FIVE SETS BE AVAILABLE FOR STUDENT SUPPLEMENTAL READING.

| | |
|---|---|
| So You're Going to Take A Radioactive Drug | Abbott Laboratories<br>Publications Department<br>North Chicago, Illinois 60064 |
| Radioisotopes in Medicine | Abbott Laboratories<br>Publications Department<br>North Chicago, Illinois 60064 |
| Brain Scan Procedure Manual<br>Dr. James Quinn, III | Abbott Laboratories<br>Publications Department<br>North Chicago, Illinois 60064 |
| Atomic Energy, 1970<br>Matthew Gaines | Grossett & Dunlap, Inc.<br>Subs. of National General Corp.<br>51 Madison Avenue<br>New York, New York 10010 |
| Atoms Today and Tomorrow, 1970<br>Margaret O. Hyde | McGraw-Hill Book Company<br>330 West 42nd Street<br>New York, New York 10036 |
| The Atom and Its Nucleus, 1961<br>George Gamow | Prentice-Hall, Inc.<br>Englewood Cliffs,<br>New Jersey 07632 |
| The Story of Radioactivity, 1969<br>Colin A. Mawson | Prentice-Hall, Inc.<br>Englewood Cliffs,<br>New Jersey 07632 |

## SPECIAL MATERIALS

The following pages describe the method of preparation of special materials. They are in experiment number order and numbered.

If these materials are carefully prepared, and stored, they can be permanent. Care in this regard can simplify subsequent class preparations.

Special note about liquid samples: The amounts described in the text are; (1) for phosphorous-32, 10 microcuries in 5 ml of solution and (2) for carbon-14, 50 microcuries in 5 ml of solution. If chemicals are obtained in other concentrations, quantity corrections will be needed.

### Syringe vs. Propipetter

Since pipetting should not be done by the mouth, one can either purchase a propipetter, or, one can use the syringe with a rubber stopper. With a little practice students will learn to control the liquid level in the pipette. The syringes used are 20 ml plastic disposable - available from local pharmacies.

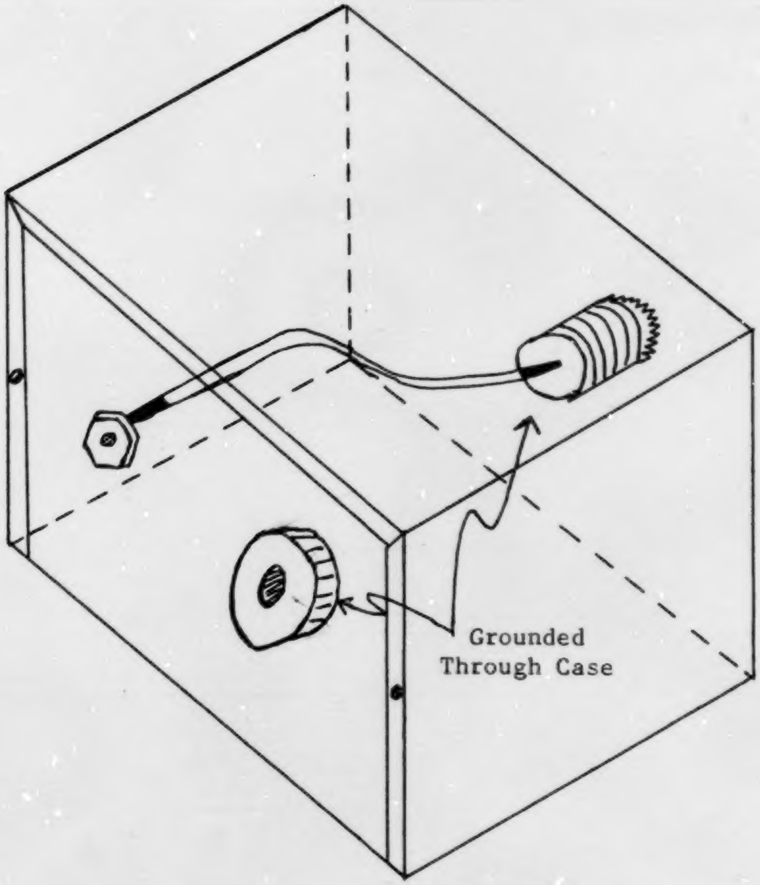
### G-M Tubes

The G-M tube used here was chosen because its operating voltage is low (450 volts), it has a long plateau, and even more important, it will respond to alpha radiation. The best source of these tubes we could locate is Thornton Associates. One or two spare tubes may be advisable although ours are still operating after two years of use.

## G-M Tube Adaptor

Because we wanted to use the Thornton G-M tube with several different scalers, it was necessary to develop an adaptor. This consists of a Bud Minibox, No. CU-3000-A, with a Co-ax Receptable Jack type SO-239 on one side, with a Tip Jack type 1505 and a Banana Jack type 1508 on the other.

The center terminal of the Co-ax Receptable is connected to the insulated Tip Jack. The Banana Jack is grounded as is the outer connection of the receptacle. (See diagram below.)



201

Made up cable may be obtained from Nuclear-Chicago, or parts purchased from Newark and assembled at school. While preparing this unit, also prepare the bell switch for Experiment 2-5.

### Disc Set

The radioactive discs were obtained from The Nucleus. We used set S-7 plus a blank disc. (A disc with no radioactivity.) This provided the alpha, beta, gamma, and "none" sources needed to develop the ideas of Chapter 2.

### X-Ray Film

We were able to find only one source of X-ray film in a form that fit our needs. That was Atomic Corporation of America. This film is in a black plastic package which permits development without a darkroom. The developing and fixing chemicals are available from the same source.

### Liquid Radioisotopes

Amersham-Searle has been our source of carbon-14, phosphorous-32 and planchets. These are available from other sources.

### Experiment 2-2: Cloud Chamber

A ¼" hole should be drilled in the side of the cloud chamber as shown in Figure 2-5 of the textbook.

### Scaler Purchase Hints

Desirable features:

1. High Voltage power supply
   a. Variable from 0 volts
   b. High voltage on-off ability
2. 60 cycle test signal
3. Internal timer with automatic count stop at desired time.
4. Plug for electric timer if not built in. The timing unit may be self contained as in The Nucleus 500 or separate as with Nuclear-Chicago's Unit.

## Experiment 2-11, 2-12: Solution Conductivity

Conductivity stoppers can be made by using a two hole rubber stopper that will fit a small vial (volume about 10 ml). Put small carbon rods through the stoppers and seal with rubber cement. Alligator clips and wires can be attached to the carbon rods.

## Experiment 3-3, 3-4: Flour Beetles

Tribolium (flour beetles) can be easily raised in the laboratory. Of the over twenty species of Tribolium, the two most common are Tribolium confusum and castaneum. They can be easily told apart by the antenna. On Tribolium castaneum the last three segments are large and equal in size, the rest being smaller but equal in size. This is called a club antenna. The antenna of Tribolium confusum taper from being large at the tip to small at the connecting end, each segment smaller than the previous one. (See figure on page 198.)

Appropriate containers for the beetles are plastic vials with snap cap covers. Vials for raising males and females separately should be about seven drams in size. Breeding vials should be larger, approximately twenty drams.

Their nutrient is a simple mixture of whole wheat flour supplemented with brewer's yeast in a ratio of nine to one, or approximately 5%. The flour and yeast should be sterilized for one hour at about 165 C. For dehydrated yeast, powder in a mortar and pestle.

Since the media in which the flour beetles live consists of fine particles, all the various stages of the life cycle can be easily separated by the use of sieves of various size meshes.

The Tribolium will arrive from the supply source in separate vials, one containing males and the other females.

After preparing the media, fill a breeding vial half-full of the media and add several Tribolium of both sexes to the vial. Puncture the plastic cap with a teasing needle for aeration. The females will begin laying fertile eggs in the first day they are placed together. They reach a maximum egg-laying capacity at ten days and will lay ten or twenty eggs a day for the next four or five months. Incubated at 30°C in 60% relative humidity, the average number of days for each of the stages of the life cycle are the following: egg - 3½ days, larvae - 17½ days, Pupa - 5 days. The eggs of the insect are oblong, averaging about 0 60 mm x 0.35 mm in length and width. Larval length, 6 to 7 mm, color mostly very light tan. Pupa are mostly light tan, but darken toward time of emergence.

The sex of Tribolium is easily discerned during the pupa stage. On the ventral posterior are genital lobes. The genital lobes of the female are larger than those of the male and the points protrude at an angle. The genital lobes of the male are smaller with rounded points and no angle. (See figure.)

After the twenty-first day, examine the breeding culture media for the presence of pupa. Examine each day after. They can be placed under the microscope and examined with low power for sexing. Males and females are then placed in separate seven dram vials half-filled with sterile media.

During the life cycle the larvae undergo five to eleven instars, with the average being seven or eight The imagoes are long-lived. With proper humidity and temperature some have lived as long as three and a half years, although their active sex life is much shorter. Stocks of Tribolium require little care. At room temperature a culture will maintain itself from four to six months before it is necessary to replace the media. Of course, weekly changes of the media will result in a more healthy culture because metabolic products accumulate in the flour, making it gummy in consistency, and sometimes trapping the beetles

Both the larvae and the adults are active. The adult has a well-developed set of wings and will use them on occasion. The adults can climb the side of a glass bottle which has had flour in it

Biologists throughout the nation are discovering that Tribolium is one of the easiest organisms to raise in the laboratory, and they make excellent subjects for studies on insect life cycles, genetics, and radiation. They have also been used extensively in population studies.

In breeding cultures it should be noted that the motile stages (larvae and adults) are cannibalistic on eggs and pupa. In addition to this, protozoan parasites and mite infestations are the two most likely things to watch for that might be harmful to the cultures. (See diagram on page 198.)

## Experiment 3-7 and all others using radioactive liquid - Safety Trays & Liners

Safety trays should be shallow trays of non-porous material such as cafeteria trays.

Disposable diapers make excellent safety tray liners.

## Experiment 4-8: Amount of Radiation

The samples may be made by dissolving uranyl acetate or uranyl nitrate in water. Use an eye dropper and add drops to a planchet. (Planchets with concentric rings work the best.) The samples are dried and counted. By careful addition of the drops one can get the samples to vary such that the second sample is twice the first, 3rd sample three times the first, etc. The unknowns are prepared with the same materials and techniques.

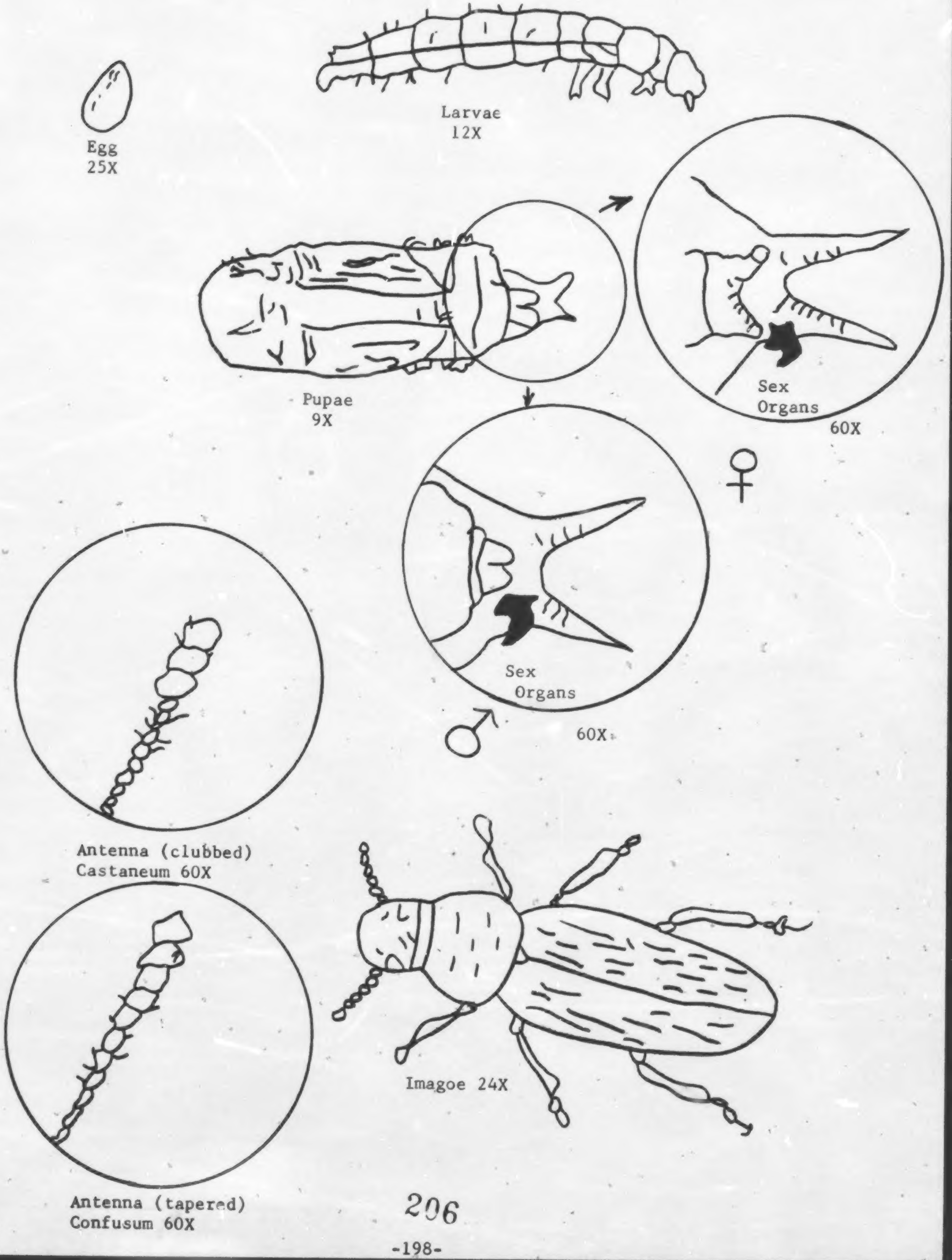
## Experiment 4-9: Radiation Spheres

The spheres should be relatively small - no larger than 6 inches in diameter. Some toy manufactures use suitable units in production. Two of these are Gam time, Inc., 45 Kensico Drive, Mt. Kisco, New York 10549, and Remco. At least one hosiery manufacturer use spheres in packaging.

A threaded rod along a diameter of the sphere and through the center of the hemispheres will serve to both support the radioactive sample and hold the spheres together.

A spherical piece of polystyrene mounted at the center of the support rod should be painted 4 or 5 times with a saturated Uranium Acetate and Methanol solution. Be sure to glue numbered labels at random locations for student tests.

# TRIBOLIUM LIFE CYCLE AND IDENTIFICATION


Egg
25X
Larvae
12X
Pupae
9X
Sex
Organs
60X
♀
Sex
Organs
♂
60X
Antenna (clubbed)
Castaneum 60X
Antenna (tapered)
Confusum 60X
Imagoe 24X

## Experiment 6-1: Tracers

The tracer slab is easily made but can become a permanent unit with care. The front sheet should be a copy of the graph included here. (See next page.) The front and back can be cut from corrugated cardboard. The elements of the maze are cut from strips of wood ½ inch thick.

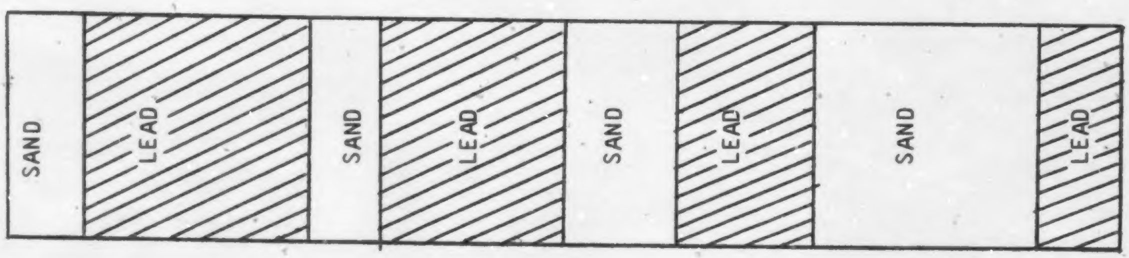
An attached sample sheet shows the shape and placement of the elements. This is a full sized drawing. The elements should be glued in place on one piece of corrugated board. The second sheet of corrugated board can then be glued on the front.

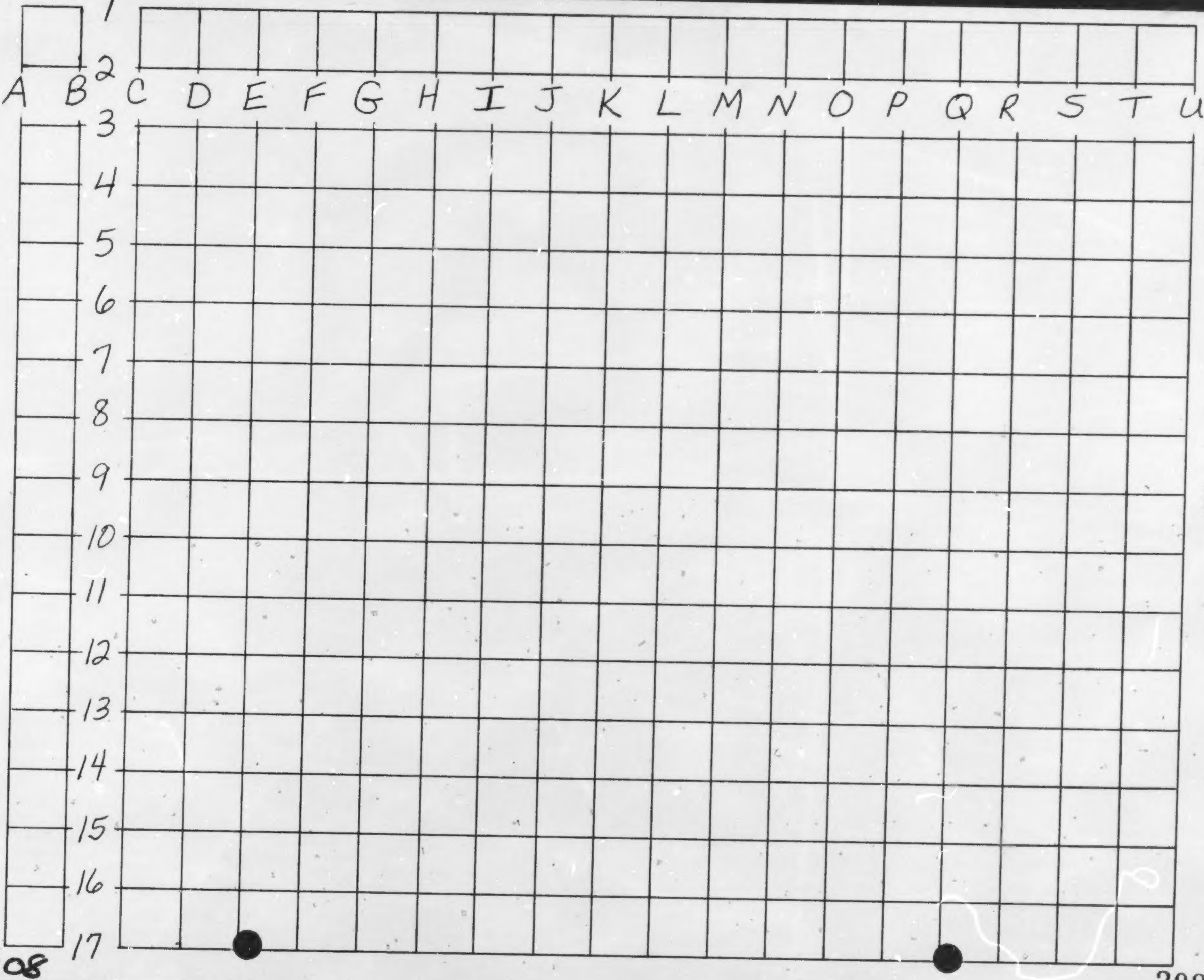
When the glue has dried holding the elements to both the front and back, the graph may be attached to the front. This may be done with double surfaced plastic tape or glue.

Remember the edge of the slab with one entry port is the top.

## Experiment 7-1: Ingot preparation

This consists of a rectangular box with a cover about 2" x 1" x 14". The box should be divided into various size compartments. These should be alternately filled with sand and lead shot.




1
2
A
B
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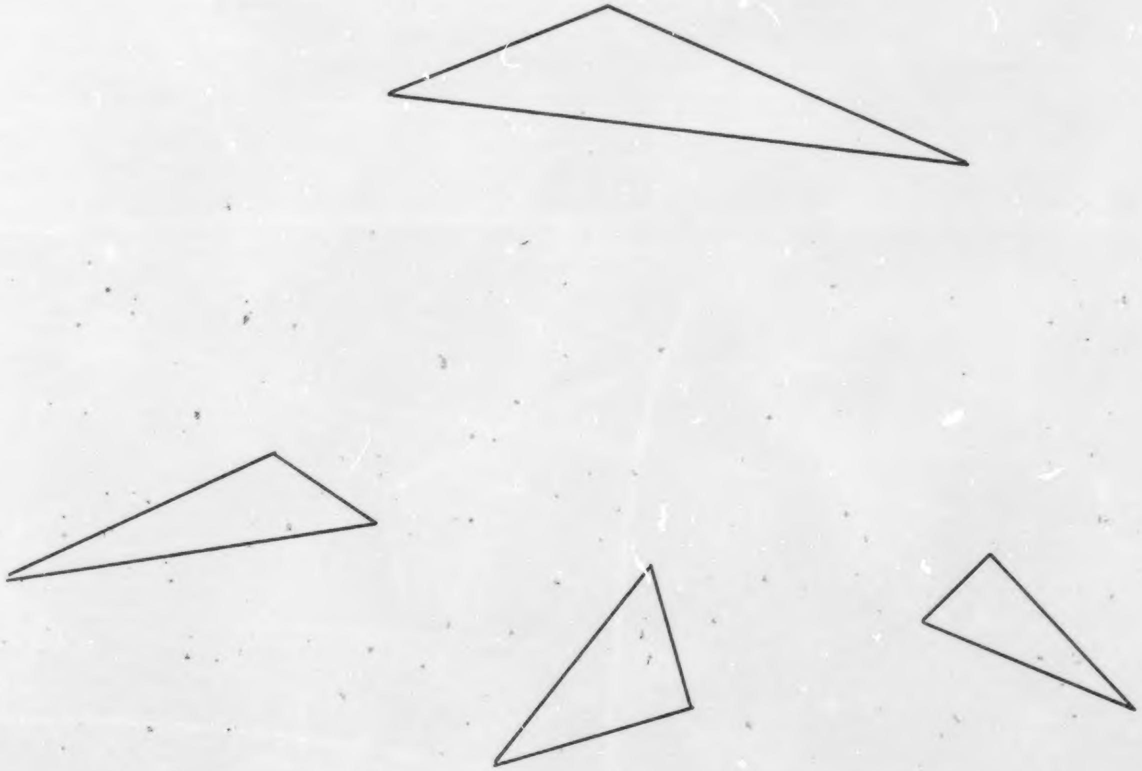

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To insure no shifting of aggregates, the compartments can be small plastic boxes - or cardboard separators can be used and the large box filled with hot wax or plaster of paris.

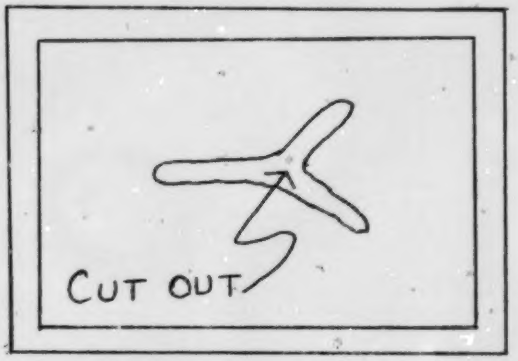
Experiment 7-2: Unknown

The unknown can be prepared by placing 2, 3, 4, or 5 lead sheets between two cardboard shields and taping the edges so that the lead sheets cannot be seen.

Experiment 7-3: Smaller Size X-ray Film and Objects to be X-rayed

The special size X-ray film may be ordered from Atomic Corporation of America. It is possible to cut the larger packets in half and seal the ends with black plastic electrician's tape. THIS MUST BE DONE IN COMPLETE DARKNESS.

The objects to be X-rayed can be prepared by cutting a pattern in a lead sheet. This should then be sandwiched between two pieces of cardboard and secured with tape.



The Kodak Velox paper can be obtained from a photographic supply house along with the developer and fixer. Mixing and developing directions are on the package.

Experiment 8-6: Plant Nutrient Solutions

Plant nutrient solutions may be prepared according to the following table. Part II and III show component preparation.

## PART I

| Materials | Solution A<br>(ml) | Phosphorous Deficient Solution B (ml) |
|---|---|---|
| $Ca(NO_3)_2 \cdot 4H_2O$ | 10 | 10 |
| $KNO_3$ | 10 | 10 |
| $MgSO_4 \cdot 7 H_2O$ | 10 | 10 |
| $KH_2PO_4$ | 10 | |
| $CaCl_2$ | 10 | 10 |
| KCl | 10 | 10 |
| Iron Chelate | 10 | 10 |
| Trace elements | 10 | 10 |
| Distilled water | 920 | 930 |
| Total | 1000 ml | 1000 ml |

## Part II

The solution components may be prepared according to the following table.

| | gm/100 ml |
|---|---|
| $Ca(NO_3)_2 \cdot 4 H_2O$ | 11 8 |
| $KNO_3$ | 5.0 |
| $MgSO_4 \cdot 7 H_2O$ | 1.4 |
| $KH_2PO_4$ | 1.4 |
| $CaCl_2$ | 5.6 |
| KCl | 0.8 |
| Iron Chelate | 0.5 (Iron ethlenediaminetetra-acetic acid) |

## Part III

The trace element solution should be prepared in two steps.

| Step 1 | gm/100 ml |
|---|---|
| $ZnSO_4 \cdot 7\ H_2O$ | 2.2 |
| $CuSO_4 \cdot 5\ H_2O$ | 0.8 |
| $Na_2MoO_4 \cdot 2\ H_2O$ | 2.5 |

| Step 2 (Using solutions of trace elements Step 1) | |
|---|---|
| $ZnSO_4 \cdot 7\ H_2O$ | 10 ml |
| $CuSO_4 \cdot 5\ H_2O$ | 10 ml |
| $Na_2MoO_4 \cdot 2\ H_2O$ | 10 ml |
| $MnCl_2 \cdot 4\ H_2O$ | 1.8 gm |
| $H_3BO_3$ | 2.8 gm |
| Distilled water | 969 ml |
| Total volume | 1000 ml |

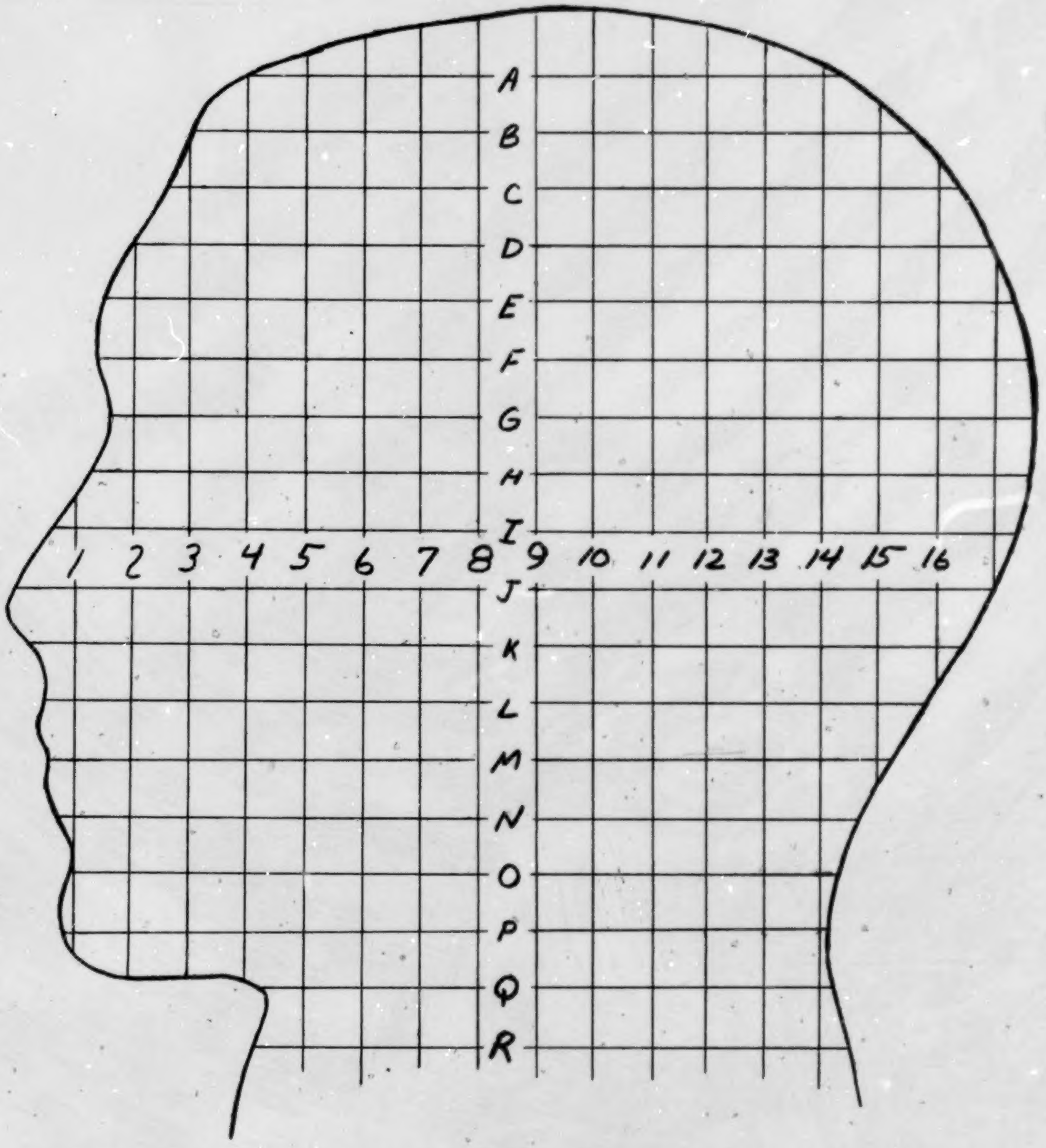
## Experiment 9-1: Brain Scan Model

An outline of a human head is given. This can be traced or copied and used as a cover for the model. A piece of cardboard can be selected the same size as the paper on which the outline is copied. Prepare a saturated solution of uranyl nitrate. Place a few drops in a selected location on the cardboard.

When the cardboard is dry, place the copy of the head over the doped surface and run a strip of masking tape around the edges. A complete seal will reduce chances of laboratory contamination if small nitrate particles should flake off.

## Experiment 9-2: Kidney model

Copy or trace the kidney outline given on a sheet of graph paper. Select a piece of cardboard the same size as the sheet of graph paper and trace the kidney outline from the graph paper onto the cardboard.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Select a place on one of the kidneys for a disorder and circle. Paint all of the kidney, except the area of disorder with the saturated solution of uranyl nitrate prepared for Experiment 9-1, Brain Scan. Be sure to paint only inside the kidney outline and outside the disorder area.

When the cardboard has dried, tape the graph paper over the painted surface and tape the edges. A complete seal will reduce the likelihood of laboratory contamination if the nitrate particles should loosen.

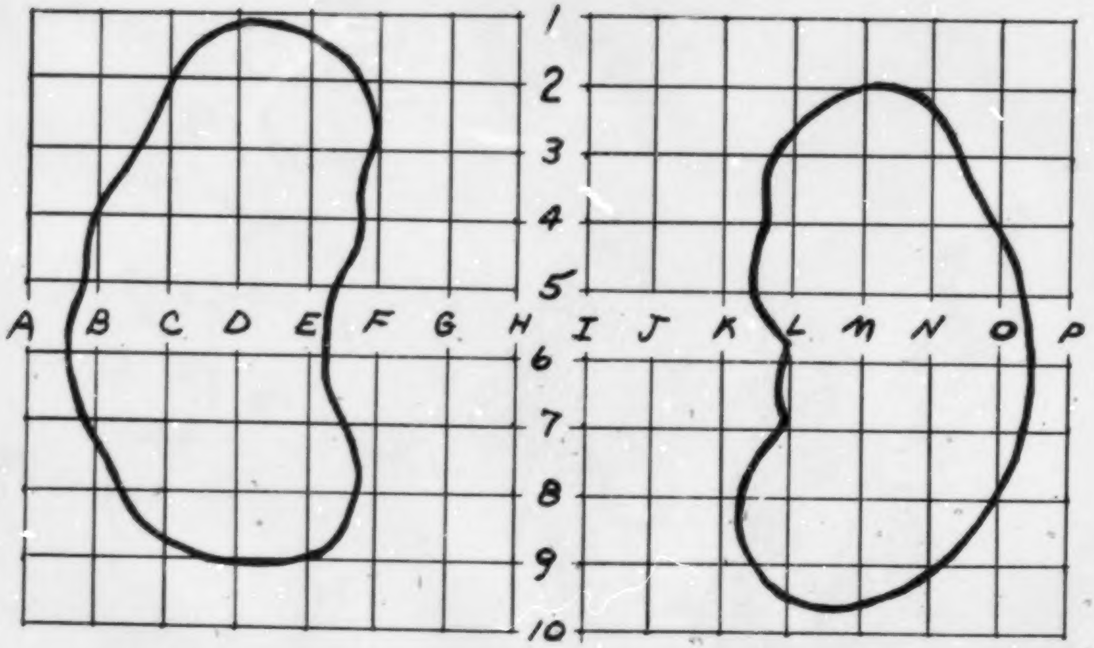
## Experiment 9-6: Solutions & Uptake Sponges

| Solutions | Make-up |
|---|---|
| A | 2-propanol |
| B | 50% water - 50% methanol |
| C | Water |
| D | Methanol |

### Uptake Sponges

One-half inch square cut from 1/16 inch sponge sheet (cotton may be used to replace sponge). Prepare a saturated solution of uranyl acetate in methanol.

Place 4 drops of the saturated solution on each square and allow it to dry before using.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## EQUIPMENT AND MATERIALS

KEY:

1. Code refers to supplier's list on the last page.
2. Chapter & Experiment - First number is the chapter number and the experiment number is in parenthesis.
3. Number refers to the number needed for a class of 24 for Chapters 1-6. It refers to the number needed per group for the self-pacing Chapters 7-9.

### I - Permanent Equipment

| Item | No. | Chapter & Experiment | Code |
|---|---|---|---|
| Aerator Systems | 2 | 3 (9) | |
| Sets of Aluminum Shields | 12 | 2 (6)<br>4 (4,5,6)<br>5 (2) | B |
| Aspirator | 1 | 7 (11)<br>8 (5) | |
| Battery (1½ v) | 12 | 2 (5) | |
| Beakers (15/20 ml) | 2 | 8 (4)<br>9 (4,5) | |
| Beakers (30 ml) | 12 | 3 (8)<br>5 (1,3)<br>8 (4) | |
| Beakers (100 ml) | 6 | 7 (6)<br>8 (3,4) | |
| Beaker (150 ml) | 1 | 7 (9) | |
| Beaker (250 ml) | 1 | 8 (8) | |
| Large Beakers (400 ml) | 24 | 2 (2)<br>3 (8,9)<br>7 (7)<br>8 (7,8) | |
| Small Bottles/Screw caps, about 5 ml | 8 | 7 (6) | |
| Bunsen Burner | 12 | 3 (9) | |
| Cardboard Shields | 12 | 4 (4,6)<br>7 (2) | B |
| Calibrated Shield/Sample Board | 12 | 2 (6,7,8,9,10)<br>4 (3,4,5,6)<br>7 (2) | B |
| Camel Hair Brush | 12 | 3 (3,4) | |
| Cesium 137 (.5μ c) (Disc) | 1 | 7 (9) | E |
| Clamp, buret | 12 | 3 (8)<br>4 (1,2,7,8)<br>7 (4,11,12)<br>8 (1,4,5,6)<br>9 (4,6) | |
| Clamp, Screw-type hose | 1 | 7 (11)<br>8 (5) | |
| Clock/sweep second hand | 1 | 4 (1)<br>8 (1) | |
| Cloud Chamber | 12 | 2 (2) | J |
| Conductivity Stoppers | 12 | 2 (11,12) | SM |
| Conductivity Vials, 5 to 10 ml | 12 | 2 (11,12) | SM |
| Cork for Hydrometer | 12 | 5 (3) | |
| Crucible, 00 | 1 | 8 (5) | |

| Item | No. | Chapter & Experiment | Code |
|---|---|---|---|
| Cylinder, Aluminum | 12 | 4 (7) | TG |
| Cylinder, Cardboard | 12 | 4 (7) | TG |
| Cylinder, Lead | 12 | 4 (7) | TG |
| Discs, radioactive | 12 | 2 (1,2,3,4,6,7,8,10) | A |
|  |  | 3 (1) |  |
|  |  | 4 (3,4,5,6,7) |  |
|  |  | 6 (1) |  |
|  |  | 7 (1,2,3,4) |  |
| Dip Net | 1 | 3 (9) |  |
| Dissecting Kit | 12 | 3 (9) |  |
|  |  | 9 (3) |  |
| Dosimeter (0-200r) | 12 | 2 (4) | I |
| Dosimeter (0-200mr) | 25 | 1 (1) | I |
|  |  | 2 (2,4) |  |
|  |  | 3 (2) |  |
| Dosimeter Charger | 1 | 1 (1) | I |
|  |  | 2 (1,4) |  |
|  |  | 3 (2) |  |
| Electroscope | 1 | 2 (3) | E |
| Erlenmeyer Flask (250 ml) | 3 | 8 (5,7) |  |
| Felt pen | 1 | 2 (3) |  |
| Filtering Flask (250ml) | 1 | 7 (11) |  |
| Flashlights | 12 | 2 (2) |  |
| Forceps | 12 | 3 (7) |  |
|  |  | 5 (1) |  |
|  |  | 7 (5,6) |  |
|  |  | 8 (8) |  |
|  |  | 9 (6) |  |
| Funnel | 12 | 5 (1) |  |
|  |  | 9 (5) |  |
| Funnel, Separatory (100 ml) | 1 | 5 (3) |  |
|  |  | 7 (11) |  |
| Fur, piece of | 1 | 2 (3) |  |
| Gammator | 1 | 2 (4,12) | D |
|  |  | 3 (1,3,4,5) |  |
|  |  | 7 (3,10,11) |  |
|  |  | 8 (2,3,9) |  |
| Germinating Soil |  | 3 (5) |  |
| Glass Bends, Right angle 4 short/2 long |  | 8 (5) |  |
| Glass Tubing (6 mm) | 1 | 8 (5) |  |
| Gloves, Heavy | 6pr | 2 (2) |  |
| Graduate (10 ml) | 1 | 9 (6) |  |
| Graduated Cylinder (25 ml) | 12 | 5 (1,3) |  |
|  |  | 7 (7) |  |
| Graduated Cylinder (50 ml) | 2 | 7 (8) |  |
| Hand Lens | 12 | 3 (3,4) |  |
| Head Model | 1 | 9 (1) | SM |
| Heat Lamps | 6 | 3 (7,8) |  |
|  |  | 4 (2) |  |
|  |  | 5 (3) |  |
|  |  | 7 (5,6,11) |  |
| Hydrometer Jar (12"-18" high x 2" dia.) | 12 | 5 (3) |  |
| Ingot | 1 | 7 (1) | SM |
| Jars (wide mouth) 1 gal. | 2 | 3 (9) |  |
| Kidney Model | 1 | 9 (2) | SM |

| Item | No. | Chapter & Experiment | Code |
|---|---|---|---|
| Kitchen Sieve | 12 | 3 (3,4) | |
| Lead Shields, sets of | 12 | 2 (6,9,10)<br>3 (2)<br>4 (4,5,6)<br>5 (2)<br>7 (2) | B |
| Light Source | | 8 (5,6,7,8) | |
| Magnet, Horseshoe | 36 | 2 (10) | |
| Mocrometers or Calipers | 2 | 4 (4,5) | |
| Milliammeter (0-25 mm) A.C. | 1 | 2 (11,12) | K |
| Minigenerator Cs137/Ba137 | 2 | 3 (8)<br>4 (1,2)<br>7 (6)<br>8 (1) | F |
| Minigenerator Sn113/In113 | 2 | 3 (7)<br>5 (1)<br>7 (8)<br>9 (4) | F |
| Minigenerator Sr90/Y90 | 2 | 3 (8)<br>4 (2)<br>7 (5)<br>8 (4) | F |
| Needle with Radioactive Tip | 12 | 2 (2) | J |
| Objects to be "X-rayed" | 4 | 7 (3) | SM |
| Overhead Projector | 1 | 2 (3) | |
| Petri Dishes (11 cm diam.) | 10 | 8 (9) | |
| Pipette (1 or 2 ml) Dropping | 12 | 2 (2)<br>3 (7,8)<br>5 (1)<br>8 (5,6) | |
| Pipettes (1 ml) | 2 | 5 (3)<br>8 (4,7) | |
| Plastic Ring | 1 | 8 (4) | TG |
| Potentiometer, 0-100K | 1 | 2 (11,12) | K |
| Power Source (0-5 v AC) | 1 | 2 (11,12) | E |
| Pro-Pipeter Bulb | 2 | 8 (4,7) | SM |
| Radiation Spheres | 12 | 4 (9) | SM |
| Radioactive Samples, Unknown | 12 | 4 (8) | SM |
| Radioactive Samples, Known | 12 | 4 (8) | SM |
| Razor Blade | 1 | 8 (6,7) | |
| Rings, Small to hold Funnels | 2 | 9 (5) | |
| Ringstand | 12 | 3 (8)<br>4 (1,2,7,8)<br>7 (4,11,12)<br>8 (1,4,5,6)<br>9 (4,5,6) | |
| Rubber Animals, Hollow (50 ml inside vol.) | 1 | 9 (4) | TG |
| Rubber Rod | 1 | 2 (3) | |
| Rubber Sheet (20 cm x 4 cm) | 2 | 7 (4) | |
| Rubber Stopper (6½-7) 2 hole | 1 | 8 (5) | |
| Rubber Stopper, 1 hole, for Filtering Flask | 1 | 7 (11) | |
| Ruler, Millimeter | 12 | 2 (10)<br>3 (5)<br>4 (9)<br>5 (3)<br>7 (2,4,7) | |

| Item | No. | Chapter & Experiment | Code |
|---|---|---|---|
| Safety Tray | 12 | 3 (7,8,9)<br>4 (1,2)<br>5 (1,3)<br>7 (5,6)<br>8 (1,4,5,6,7,8)<br>9 (3,4,5,6) | SM |
| Sample Holder | 12 | 2 (6,7,8,10) | TG |
| Samll Samples - glass, wood, metal (shiny, rusty), concrete | | 3 (8) | TG |
| Scaler, G-M tube, Timer | 12 | 2 (5,6,7,8,9)<br>3 (1,2,7,8)<br>4 (1,2,3,4,5,6,7,8,9)<br>5 (1,2,3)<br>6 (1,5,6)<br>7 (1,2,4,5,6,7,8,9,12)<br>8 (1,4,5,8)<br>9 (1,2,3,4,5,6) | AB |
| Scissors | 2 | 3 (5) | |
| Seed Growing Trays | 2 | 3 (5) | |
| Stirring Rod | 3 | 5 (3)<br>7 (6,8)<br>9 (6) | |
| Stopwatch | 1 | 7 (7) | |
| Support Rod for Rubber Sheet | 2 | 7 (4) | |
| Survey Meter | 4 | 3 (7) | I |
| Switch, Bell | 12 | 2 (5) | |
| Syringe (20 ml/large bore needle) | 12 | 2 (1)<br>3 (7)<br>5 (3)<br>7 (8)<br>8 (5) | SM |
| Syringe and Needle 2 ml | 6 | 2 (1)<br>7 (8)<br>8 (5)<br>9 (3,4) | SM |
| Tee Joint (6 mm) | 1 | 7 (7) | |
| Test Tube (10 mm) | 12 | 3 (7)<br>8 (6)<br>9 (6) | |
| Test Tubes (18 x 150 mm) | 24 | 5 (1,2,3)<br>7 (11)<br>9 (5) | |
| Test Tube (25 x 200 mm) with Stoppers to fit | 5 | 8 (8) | |
| Test Tube Rack | 12 | 3 (7) | |
| Tracer Slab | 12 | 6 (1) | SM |
| Tubing (6 mm x 2½ meters) | 1 | 7 (7) | |
| Tubing, Rubber (6 mm) | | 8 (5) | |
| Tubing, Vacuum (2 ft.) | | 7 (11) | |
| Uranium Ore, Samples | 12 | 5 (2) | M |
| Vacuum Cleaner, Tank-Type | 1 | 3 (2,7,12) | |
| Vials for Irradiating Seeds (about 10 ml) | 24 | 3 (5)<br>7 (8)<br>8 (9) | |

| Item | No. | Chapter & Experiment | Code |
|---|---|---|---|
| Waste Can, Radioactive | 1 | 2 (1)<br>3 (7,8,9)<br>4 (1,2)<br>5 (1,3) | |
| Watch Glasses | 8 | 7 (6,10) | |
| Wash Bottle | 6 | 2 (11,12) | |
| Weighthanger and Weights | 2 | 7 (4,5,11) | |
| Wire Screen, 3" x 3" | 1 | 3 (2,7,12) | |
| Wooden Blocks | 24 | 3 (8) | TG |
| II - Consumable Supplies | | | |
| Acetone (25 ml) | 25ml | 7 (10) | |
| Alcohol (Methyl & Isopropyl) | | 2 (2,10)<br>9 (6) | |
| Aluminum Foil | | 7 (11)<br>8 (7,8) | |
| Ammonium Hydroxide | | 5 (1) | |
| Ammonium Nitrate | | 5 (3) | |
| Anethetic Solution | | 3 (9) | |
| Autoradiograph Kit - X-Ray film in light-proof package | 60 | 2 (1)<br>3 (9)<br>7 (3)<br>8 (5,6,7) | C |
| Bread | | 8 (2) | |
| Calcium Hydroxide Solution | | 8 (5) | |
| Carbon-14 (Sodium Carbonate) (50μCi in 5 ml) | | 8 (5,8) | H |
| Cardboard Strips | | 7 (5) | TG |
| Cellophane (Red, green, blue) | | 8 (8) | |
| Chloroform | | 9 (3) | |
| Chromatography Paper, Whatman #1 1" wide | 1 roll | 5 (3) | |
| Cloth, Cotton, 1" squares | 4 | 7 (6) | |
| Cloth Strips | 1 | 7 (5) | TG |
| Coats, Lab. to be worn daily for entire semester | 25 | | |
| Copper Sulphate (1 gm) | | 2 (11) | |
| Cotton Balls | 2 | 8 (6,7) | |
| Cotton Cloth | | 9 (3) | TG |
| Detergent, cleaning glassware | | 3 (7,8) | |
| Detergents (4 powdered) | | 7 (6) | TG |
| Dilute Acid HCl or $H_2SO_4$ | | 8 (5) | |
| Dry Ice | | 2 (2) | TG |
| Dialysis Tubing, Size 36 (1 1/8" dia.) | | 8 (4) | |
| Ethyl Acetate | | 5 (3) | |
| Ferric Chloride | | 2 (12) | |
| Ferrous Chloride | | 2 (12) | |
| Film Badges | 25 | 1 (1) | B |
| Filter Paper, Sheets | 75 | 3 (2)<br>5 (1)<br>7 (1,2)<br>8 (9)<br>9 (5) | |

| Item | No. | Chapter & Experiment | Code |
|---|---|---|---|
| Salt | | 2 (11) | |
| Samples to be tested | | 9 (6) | SM |
| Sandpaper, 8½" x 11" | | 7 (5,11) | |
| Seeds | | 3 (1) | |
| Seeds ("A" & "B") Clover & Barley | | 3 (5) | |
| Sodium Hydroxide Solution | | 8 (5) | |
| Sodium Hydroxide (Solid) | | 9 (5) | |
| Sponges (Uptake) | 4 | 9 (6) | SM |
| Sugar | | 2 (11) | |
| Talcum Powder | | 3 (1,7,8,9)<br>4 (1,2) | |
| Tape, Electricians | | 8 (5) | |
| Tape, Masking | | 2 (2,10) | |
| Tissues, Wiping | 1 pkg. | 3 (7) | |
| Toothpicks, Round | 1 pkg. | 8 (3) | |
| Uranyl Acetate | ½ lb. | | |
| Uranyl Nitrate (Solid) | ½ lb. | 5 (3) | |
| Vials, Glass - Plastic Caps (1-2 dram) | 5 | 7 (10) | |
| Water, Distilled | | 2 (1,11)<br>3 (7) | |
| Wire, Hook-up | | 2 (5,11,12) | |
| Wood/cork | | 3 (1) | |
| Wood, Block 1½" square | 1 | 7 (5) | |
| Wood, Cubes - Hardwood, 1 $cm^3$ | 2 | 7 (11) | |
| Wood, Cubes - Softwood, 1 $cm^3$ | 2 | 7 (11) | |

## SUPPLIERS

| EQUIPMENT LIST CODE | SOURCE | ADDRESS |
|---|---|---|
| A | The Nucleus | P.O. Box R, Oak Ridge, Tenn. 37830 |
| B | *Searle Analytic, Inc. | 2000 Nuclear Dr., Des Plaines, Illinois 60018 |
| C | Atomic Corp. of America | 213 Glendate Blvd., Los Angeles, Calif. 90026 |
| D | Kewaunee Scientific Equip.Corp. | P.O. Box 618, Adrian, Mich. 49221 |
| E | Cenco Instruments Corp. | 2600 S. Kostner Ave., Chicago, Illinois 60623 |
| F | Union Carbide Corp. | P.O. Box 363, Tuxedo, New York 10987 |
| G | Thornton Associates, Inc. | 87 Beaver St., Waltham, Mass. 02154 |
| K | Newark Electronics | 500 N. Pulaski Rd., Chicago, Illinois 60624 |
| H | Amersham/Searle Corp. | 2636 S. Clearbrook Drive, Arlington Heights, Ill. 60005 |
| I | Civil Defense Office | |
| J | Macalster | Route 111 & Everett Tpk., Nashua, N.H. 03060 |
| M | Sargent Welch | 7300 N. Linder Ave. Skokie, Ill. 60076 |
| | Remco Industries (Frustration Ball) | Cape May, Harrison, N.J. 07029 |
| | Gametime, Inc. | 45 Kensico Dr., Mt. Kisco, N.Y. 10549 |
| | General Radioisotope Products | 3120 Crow Canyon Rd., San Ramon, Calif. 94583 |
| SM | Special Materials in Teacher's Guide | |
| TG | See appropriate experiment in the Teacher's Guide | |

*Searle Analytic was formerly Nuclear, Chicago